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主論文

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

下部白亜系，豊西・関門層群の堆積盆解析

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ABSTRACT

Neritic to fluvial sediments 6,000 m thick are distributed in the Jurassic to Lower Cretaceous Kanmon Basin in the westernmost Honshu Island, Inner Zone of the Southwest Japan. The purposes of this study are to clarify the geometry of the basin and to reconstruct the tectono-sedimentary development process of the basin. The results may provide some 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.

These groups are unconformable or partly disconformable with each other, and are considerably deformed in the northern Shimonoseki City. Because granitic plutons in the earliest Late Cretaceous age intrude discordantly into the deformed sediments, it seems certain that the deformation occurred during the short interval between the ending of sedimentation and the plutonic emplacement.

In recent years, shallow marine fossils were discovered from limestones regarded as lacustrine sediments belonging to the Wakino Subgroup. By detailed stratigraphical research, it become clear that the limestones developed in middle part of the Toyonishi Group, and these marine molluscs-bearing members are newly defined by the author as the Murotsu Formation. This neritic formation is the key both to determining the accurate depositional age of the Toyonishi Group and to understanding the sedimentary environment of the Earliest Cretaceous.

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.

Provenance and sedimentary facies analyses suggest that, during the Jurassic to the Early Cretaceous, the differential movements between the basin and the provenance were caused by the intermittent growth dip-slip movement of the Nagato Tectonic Zone. 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.

In the Toyota area of the Yamaguchi Prefecture, basin formational structures, such as the Nagato Tectonic Zone, were cut by faults newly defined as Toyota Tectonic Line. Features of these deformational structures (folding and faulting) are different on both sides of the tectonic line. Because the tectonic line may extend to the Kokura-Tagawa Fault in north Kyushu and deformation structures of the Upper Mesozoic formations seem to have been formed under NS compressional strains caused by left-lateral strike-slip movement of an en-echelon fault, it is possible to propose a deformation model of left-lateral strike-slip movement of the Toyota Tectonic Line, prior to the Late Cretaceous igneous activities.

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.

Contents

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 underlying "Kiyosue plant bearing beds" were included in the later defined Toyonishi Group (Matsumoto, 1949). Since the term of Inkstone Group was confused in usage so that the Kanmon Group was proposed by Matsumoto (1951a).

In recent years, Yoshidomi and Inoue (2001) reported corals, nerineid gastropods, bivalves and cidarid echinoids from limestones regarded as lacustrine sediment belonging to the Kanmon Group, and suggested that these limestones are marine facies of the Toyonishi Group. Thus, a re-examination of the stratigraphy and depositional environment of the Toyonishi Group is needed.

These Jurassic to lower Cretaceous groups overlie unconformably on Paleozoic and Triassic formations, and 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), 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, 1951a; Ueda, 1957; Hase, 1958, 1960; Takahashi et al., 1965, 1966; Hirano, 1971, 1973; Takahashi and Mikami, 1975). 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
5. Deformation process of the sediments

Through detailed investigation of stratigraphy, clastic components, facies analysis and geologic structures of the Yoshimo-Kikugawa area.

Sequence stratigraphical studies have recently been carried out. 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 the sedimentary basin resulted from tectonic movements.

Because tectonic movements of the basins may be 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 and Suczek, 1979; Valloni and 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 on.

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 in the middle part of the Kanmon Basin. From a tectonic viewpoint, the East Asian continental margin was characterized by remarkably developed NNE-SSW trending large-scale faults, most of which originated in the Late Jurassic to Early Cretaceous (Chen and Qin, 1989; Xu et al., 1989; Zhou et al., 1989; Natal'in, 1993; Okada and Sakai, 1993). All of the sedimentary basins have been developed in the northeast side of these faults. These basins include the Umsong Basin, the Kyongsang Basin, the Kanmon Basin, the Kenseki Basin and Chichibu Basin from northwest to southeast.

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 and Wu, 1995).

There are mainly two theories proposed: model of strike-slip movement and model of tilting movement of half-graben.

The clarification of the tectonic setting and deformation process 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.

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II. Geologic Outline

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

A. Basement rocks

The basement rocks of the Late Mesozoic formations can divide into three groups mainly, Sangun-Renge Belt, Akiyoshi Terrane and Suo Terrane (Fig. 3). In Yamaguchi Prefecture, the Sangun-Renge Belt does not exposed except for Nagato Tectonic Zone, and the Triassic formations are widely distributed in western part of the Akiyoshi Terranes.

1. Nagato Tectonic Zone

The Nagato Tectonic Zone constitutes a narrow belt with an extension of about 35 km, only few kilometers width, trending from NNE to SSW in western Yamaguchi Prefecture (Matsumoto, 1949). This tectonic zone become a boundary of the Akiyoshi Terrane and the Upper Mesozoic formations, and contact with former by faults and 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. These rocks are exposed as lenticular distribution, and are separated into five areas, i.e. Misumi, Dai, Nishiichi, Toyoga-take and Ozuki from north to south (Murakami and Nishimura, 1979). And it is known that igneous rocks of the Nagato Tectonic Zone have low K_20/Na_2O ratio (Murakami and Nishimura, 1979).

Assemblages of the tectonic zone constituent rocks are different in the north and the south. Misumi and Dai areas belong to the former, and other areas are contained in latter. Serpentinites are dominated in the north side, and amphibolites and orthogneisses were only reported from this area. On the other hand, the Paleozoic formations and crystalline schists are widely distributed in the south side.

The Paleozoic formations of the Dai area are named Dai Group (Takahashi and Kimura, 1965), and of the Nishiichi, Toyoga-take and Ozuki areas are called Toyohigashi Group (Takahashi et al., 1965).

From recent study, high - P/T type schists of the Toyoga-take area show about 264 to 303 Ma geologic ages (Nishimura et al, 1983), and the Late Carboniferous radiolarians are 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 and Tamura, 1989). These newly obtained 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 zone.

On the other hand, Early Permian radiolarians were found out from an allochthonous blocks of bedded chert of the Toyohigashi Group in the Toyoga-take area, Toyota-cho (Isozaki and Tamura, 1989). Based on the fact and the total lithological assemblage of the unit, the Toyohigashi Group can be properly correlated with the Middle to Late Permian accretionary complex of the Akiyoshi Terrane, which is distributed not merely in the east of the Nagato Tectonic Zone but also in the Hida Marginal Belt.

2. Sangun metamorphic rocks

Sangun metamorphic rocks consist mainly of pelitic to psammitic schist and basic schist accompanied with quartz schist, metagabbro and serpentinite, which are of gloucophanitic type and sporadically distributed in the Inner Zone of Southwest Japan (Kobayashi, 1941).

In recent study, it become clear that so-called Sangun metamorphic rocks are not single coherent glaucohpanitic terrane, but is comprised of at least three terranes with different radiometric ages, Chizu Terrane (180 Ma), Suo Terrane (220 Ma) and Sangun-Renge Belt (300 Ma) (Hayasaka, 1987; Shibata and Nishimura, 1989; Nishimura, 1989).

3. Akiyoshi Terrane

The central region of Yamaguchi Prefecture is mainly consisted from the Paleozoic formations which are divided into three geological bodies, central part of the Akiyoshi limestone Group, southeast part of the Ota Group and northwestern the Beppu and Tsunemori Groups.

The Akiyoshi limestone Group (Ozawa, 1925) is composed of limestone mainly. Basis on the biostratigraphic study of fusulina, these limestones were formed between Lower Carboniferous to Upper Permian (Ota, 1977). The Ota Group is composed of chert and sandstone with shale thin beds (Fujii, 1972). The Tsunemori Group is composed of dark shale formation with lenticular chart and limestone. The Beppu Group is composed of chert formation with small amount of sandstone and shale (Mikami, 1974), and might be continued with the Tsunemori Group originally (Fujii and Mikami, 1970).

Radiolarian and foraminifera fossils studies indicate that these formations are Permian accretionary complex.

In Kyushu district, the Paleozoic Yobuno Group (Matsushita, 1971) is distributed in Kiku peninsula and around Hirao-dai. Lithological assemblage of the group can be properly correlated with the Tsunemori Group in Yamaguchi Prefecture. Thus, it is considered that the Yobuno Formation might be a west extension of the Akiyoshi Terrane.

Distributions of the Upper Yobuno Group are separated by the Kokura-Tagawa fault (Kinoshita et al., 1954) and sub-parallel set of faults, and are shown as a left-hand en-echelon distribution.

The Paleozoic formation distributed in Wakamiya-Sasaguri areas called the Aida Formation (Kobayashi, 1941). It can be correlated with the lower Yobuno Group, basis on the lithological character.

4. 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 formation distributed in Atsu area is called the Atsu Group, and depositional age is estimated to be upper Radinian to lower Carnian. Similarly, The lower Carnian to lower Norian formations distributed in both Omine and Asa areas are defined as the Mine Group (Takahashi and Mikami, 1975a).

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

These Triassic formations contact with the Nagato Tectonic Zone by faults, and with the Permian Tsunemori and Beppu Groups by faults or covered unconformably.

B. Jurassic to Lower Cretaceous

The Jurassic to Lower Cretaceous in western Yamaguchi Prefecture are divided into four groups (Fig. 4). These groups are whole or partly unconformable with each other.

1. Toyora Group

The Toyora Group is composed of neritic shale mainly (Yabe, 1920). The distribution of the group restricted to the Kikugawa-cho in Yamaguchi Prefecture. The stratigraphy and biostratigraphy of the group are studied by Hirano (1971, 1973), and are summarized Takahashi and Mikami (1975b). The Group is subdivided into three formations correspond with one sedimentary cycle, 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 in ascending order (Hirano, 1971, 1973a, 1973b).

Lias bivalve fossils are reported from the lower Higashinagano Formation, and many ammonite fossils are also reported from the Nishinakayama Formation (Hirano, 1973). Many fossils, i.e. Ammonite, Belemnite, Inoceramus are reported from lower part of the Utano Formation, and Onychiopsis flora are frequently observed in upper part of the Utano Formation (Takahashi and 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 of the Early Jurassic, 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 area by the Kikugawa fault (Quaternary fault) trending from NW to SE.

In the Ishimachi area, these formations attain to 1,900 m, and unconformably overlies the Toyohigashi Group and metamorphic rocks of the Nagato Tectonic Zone, and are covered by Kanmon Group directly (lack of the Toyonishi Group).

In the Tabe area, the Lower Higashinagano formation contact with the Nagato Tectonic Zone. And the upper Utano Formation is covered by Toyonishi Group by clino-unconformity. Lithological character and thickness of the group varies from north to south. The south side of the Utano Formation is more coarse grained than the north side, and contained plant fossils increase from north to south. Judging from these lithological properties, it is considered that depositional environment of the north part is more deeper than south.

2. Toyonishi Group

The Toyonishi Group (Kobayashi and Suzuki, 1939) is developed mainly in Yoshimo and Utsui areas, northern Shimonoseki City, Yamaguchi Prefecture. The Group subdivided into two formations basis on 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 lower Kiyosue Formation is consist of mudstone dominantly alternating beds of coaly mudstone and coarse-grained arkose sandstone, and plant fossils are abundantly contained in former. These plant fossils are 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 and Mikami, 1975b). Depositional age of the Kiyosue Formation is estimated to be uppermost Jurassic.

b. Yoshimo Formation

The upper Yoshimo Formation is consist of the alternating beds of fine-grained sandstone and mudstone accompanied with brackish molluscs fossils. It has been pointed out that the molluscs of the formation can be correlate with the one 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 earlymost Cretaceous.

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

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 older geological formations, 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, 1951a).

The former is characterized by clastic sediments intercalating small amounts of felsic tuff or tuffaceous sediments, while latter consists mainly of large-volume of andesitic to dacitic lavas and pyroclastic rocks and minor amount of rhyodacitic to rhyolitic lavas and phyroclastic rocks.

The relation of the Wakino and Shimonoseki Subgroups is so intimate that they are combined under the name of the Kanmon Group. These two subgroups are developed usually in accompaniment with each other, being in some place conformable and in others disconformable (Hase, 1958, 1960).

a. Wakino Subgroup

The Wakino Subgroup is typically subdivided into four formations, Sengoku, Nyoraida, Lower Wakamiya and Upper Wakamiya in ascending order, at the type locality of Wakino area, North Kyushu (Hase, 1958). Each formation begins with a basal conglomerate. In North Kyushu except for the Moji area, the Sengoku Formation overlies the Paleozoic Aida Formation as well as the Sangun metamorphic rocks by a remarkable unconformity. At Moji, however, the Nyoraida Formation covers the Paleozoic Yobuno Group directly. Many thrusting faults are observed near the unconformity surface of the group.

In Chugoku district, the Lower Wakamiya Formation covers various older rocks, that is, the Mine Group with a moderate clino-unconformity, the Toyora and Toyonishi Groups with slightly clino-unconformity.

Non-marine bivalves and gastropods are reported from the Wakino Subgroup by Ota (1960). Because of these non-marine fossils can not be used for international comparison, it is difficult to determine the depositional age of the Wakino Subgroup. Basis on the subgroup covered the Toyonishi Group unconformably, the ages from Valanginian to Hauterivian of the early Cretaceous are estimated. It is considered that the Sengoku Formation is a contemporaneous heterotopic facies of the Yoshimo Formation, the upper Toyonishi Group.

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 great thickness (attaining about 2,000 m in the type area) and the frequent occurrence of purple-red or variegated sediments.

This subgroup divided into four formations, Shiohama, Kitahikoshima, Sujigahama and Fukue 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 the same within each analytical error, 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 is 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 volcanics indicate that the igneous activities, prior to the Late Cretaceous igneous activities, are already activated at the Albian.

4. Shunan Group

The Shunan Group is distributed in east side of Yamaguchi Prefecture mainly, overlying the Kanmon Group and pre-Cretaceous older geological formations, and usually developed in accompaniment with the Kanmon Group. It consists mainly of andesitic to dacitic lavas and pyroclastic rocks and of rhyodacitic to rhyolitic lavas and phyroclastic rocks, and small amount of tuffaceous sandstone and mudstone are intercalated. According to the properties of volcanic sediments and the reralionship of underlying and overlying formations, it can be correlated with the Yahata Formation in North Kyushu. Fission track ages of zircon in dacitic tuff and dacitic welded tuff from the Shunan Group are reported, the dacitic tuff being 94.2±7.3 Ma, and dacitic welded tuff 92.5±6.8 Ma and 85.2±5.1 Ma (Murakami, 1985). It is clear that the Shunan Group formed at the Turonian of the Late Cretaceous.

C. Granitic rocks

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

In the Yoshimo-Kikugawa area, these granitic rocks distributed in northwestern and southeastern part. The former called the Ogushi Granite and 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 and Ueda, 1966).

Granitic rocks distributed in north Kyushu divided into two bodies, the North Kyushu Main Granites and the North Kyushu East Granites, by the Kokura-Tagawa Tectonic Line (Kinoshita et al., 1954). Radiometric ages of the both side are not so different and are same with the Hiroshima Granites. The North Kyushu East Granites has lower Sr ratio, and Izawa et al. (1989) pointed out that it can be correlate with the Hiroshima Granites.

III. Descriptions of Local Stratigraphy

Being separated by the outcrop of older terrains, the intrusions of igneous rocks and blankets of younger sediments, Lower Cretaceous sediments are discontinuously distributed in west chugoku and north kyushu. Hase (1958, 1960) divided into nine areas, based on mainly distribution.

1. The Kodaijiyama - 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 - Wakamatsu area = The mountainous quarters of these four adjacent cities, Fukuoka Prefecture.
6. The Moji - Shimonoseki area = Along the Kanmon strait.
7. The Toyonishi - Utsui area = North of Shimonoseki City, Yamaguchi Prefecture.
8. The Nishiichi - Takibe - Tawarayama - Senzaki - 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.

A. Yoshimo-Kikugawa area

The main study area correspond to the Toyonishi-Utsui area. But the name of the Yoshimo-Kikugawa area is used in this study, because of that the locality name of Toyonishi isn't used currently and study area contain a distribution of the Toyora Group. The stratigraphy of the late Mesozoic rocks developed most perfectly in this area. The geological map is shown in Fig. 6. The detailed descriptions of the Toyora and Toyonishi and Kanmon Groups based on the lithology and fossils are discussed in this chapter. Localities of study area are shown in Fig. 5.

1. Toyora Group

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

a. Higashinagano Formation

(1) Basal conglomerate, alternating with coarse grained quartzose sandstone. The conglomerate is ill-sorted, consisting usually of subrounded to subangular cobbles and pebbles chert and schist, highly lithified.

(2) massive coarse to fine grained quartzose sandstone, intercalating with conglomerate which consist of subrounded granule to pebbles chert and schist.

b. Nishinakayama Formation

(1) Basal conglomerate, consisting usually of subrounded to rounded pebbles and granules chert and schist, highly lithified.

(2) Bedded mudstone with small amounts of sandstone or sandy shale.

c. Utano Formation

(1) Basal part: Coarse grained quartzose sandstone, with conglomerate consisting mainly of well rounded pebbles of chert.

(2) Main part: alternating beds of coarse to medium grained arkose sandstone and black to greenish gray mudstone, containing abundant plant fossils. Thickness of sandstone increase upward.

2. Toyonishi Group

This is exposed in Kiyosue and Kami-nanami, the western part of the study area, and in the coastal area near Yoshimo.

a. Kiyosue Formation

This formation quite resembles with the upper Utano Formation lithologically. In the type sections near Kiyosue and Utsui the Kiyosue formation begins with remarkable basal facies.

(1) Basal part: medium to coarse grained arkose sandstone, with conglomerate consisting mainly of well rounded granules and pebbles of chert (dark or milky in color).

(2) 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 conglomerate. Mudstone is prevails over others, and containing abundant plants fossils and their fragments. Sandstone is usually quartzose, massive to well bedded, partly cross-laminated, fine- to coarse grained and sometimes pebbly.

b. Yoshimo Formation

(1) lower part: alternating beds of white to light gray colored fine to medium grained quartzose sandstone and black to dark colored mudstone. They are well bedded in several centimeters to several ten centimeters order. Generally, sandstone is dominated in alternating beds, and containing abundant brackish molluscs fossils.

(2) upper part: sandstone, fine to coarse grained, white to light gray colored intercalating of granule conglomerate. A slight erosional surface is observed at the base.

3. Wakino Subgroup .

The Wakino Subgroup begins with a remarkable basal conglomerate, and it overlain on the Yoshimo Formation for parallel in the southern part, and denuded the Yoshimo Formation to angular unconformity and overlain on the Kiyosue Formation directly in the northern part. Because of the Sengoku and Nyoraida Formations are lacking, this subgroup consist from the following two formations in this area.

a. Equivalent of the Lower Wakamiya Formation

(1) Basal conglomerate: ill-sorted, subrounded to subangular cobbles and boulders sandstone and chert, occasionally limestone clasts are observed.

(2) Main part: alternating beds of medium to coarse grained quartzose and fine to medium grained calcareous sandstone intercalating conglomerate and dark to gray mudstone. They are bedded in several centimeters to several ten centimeters order, and sandstone is dominated.

b. Equivalent of the Upper Wakamiya Formation

(1) Basal conglomerate, alternating with sandstone and mudstone.

(2) Main part: alternating beds of fine to medium grained sandstone and black to dark purple colored mudstone, in several ten centimeters order.

(3) Upper part: red to magenta colored mudstone, intercalating fine to medium grained greenish gray colored sandstone. Mudstone contains nodular of lenticular calcretes sporadically.

4. Shimonoseki Subgroup

a. Shiohama Formation

(1) Basal part : alternating beds of conglomerate and sandstone. conglomerate consist of rounded to subrounded pebbles and cobbles 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.

(2) Main part: red to purple colored mudstone containing nodular to bedded calcretes, intercalating conglomerate. Around Mt. Onigajiro, mudstone color is changed to black or dark gray and calcretes are not observed.

b. Kitahikoshima Formation

Andesitic to dacitic lavas and pyroclastic rocks. Lava is mainly composed of hornblende andesite and quartz-bearing hornblende andesite,. each of them is strongly alterated in usual. This volcanic formation is so distributed continuously and well exposed that takes a role of key bed.

c. Sujigahama Formation

(1) Basal part: red to purple colored mudstone intercalating several ten centimeters conglomerate. This facies closely resembles to the upper part of the Shiohama Formation.

(2) Main part: begins with a conglomerate, ill-sorted, rounded to subrounded granules and large pebbles andesite, chert and sandstone. This part consist of normal grading unit that grading from conglomerate to shale in several meters order.

(3) Upper part: alternating beds of thick red mudstone and coarse grained sandstone, intercalating of tuffaceous silt or sandstone.

(4) Uppermost part : well-developed conglomerate and purple colored pebbly mudstone, intercalating thin red mudstone. Conglomerate consist of ill-sorted pebbles and cobbles subangular to subrounded andesite, sandstone and chert. The thickness of the conglomerate increase upward.

d. 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.

B. Murotsu area

Murotsu area is separated from other Upper Mesozoic distributions by emplacement of granitic and dioritic rocks. The Toyonishi Group and Wakino Subgroup are distributed in this area (Hase, 1958; Yoshidomi and Inoue, 2001).

Sedimentary rocks are continuously exposed along the sea side (Fig 7), and columnar section is shown in Fig. 8. These formations have E-W strike and highly dipping to the north. Small granitic or granite porphyritic dyke are observed frequently in these sedimentary rocks, and a granodiorite-porphyrite complex are widely exposed in the south of the Fig. 7. These intrusive rocks are west extension of the Ogushi Granite, and are seem to be a marginal phase of granit. Because of these intrusive rocks, the lower limit is not exposed.

The formation has been divided into four members in ascending order; Lower Mudstone Member, Middle Sandstone and Mudstone Member, Upper Limestone Member and Uppermost Sandstone and Mudstone Member (Yoshidomi and Inoue, 2001).

1. The Lower Mudstone Member (120 m)

This member consist of dark colored layered coaly mudstone, and no lithofacies variations. In the upper part of the member coarse grained arkose sandstone (38 m) are developed with large scale lamina. This sandstone are overlain by dark colored mudstone (14 m) and gray colored calcareous mudstone (8 m). The calcareous mudstone is millimeter scale alternating beds of dark colored mudstone and light gray colored calcareous mudstone. In the uppermost calcareous facies, lenticular limestones, few centimeters thick, are developed partially.

2. The Middle Sandstone and Mudstone Member (62 m)

The member consist of alternating beds of sandstone and mudstone. The thickness of the sandstone are about few centimeter, and generally show a tendency to fining upward. In the lower part of the member, limestones are developed as lenticular or alternating with clastics.

The lower part of the limestone contains large size of corals, gastropods, cidarid ecinoides abundantly. The diameter of the coral attains to a half meter, and growth direction of these corals doesn't coincide with the sedimentological above.

The upper part of the limestone are composed from biomicrite with few allochems.

3. Upper Limestone Member (44 m)

Mainly consist of limestone, gray to light gray in color, and further divided into five, Basal part (limestone), Lower part (limestone), Middle part (mudstone), Upper part (limestone) and Uppermost part (alternating beds of sandy limestone and calcareous mudstone) in ascending order.

The basal part (19 m) consist from limestone which classified into biolithite, and rich in colonial coral fossils. It is clearly observed growth direction of coral, and the direction correspond with the sedimentological upward. Original textures of the limestone are well preserved generally. But partially it is lost by contact metasomatism, and skarn minerals such as garnet, clinopyroxene and actinolite are observed.

The lower part (6 m) consist from limestone which classified into biomicrite, and rich in fossils fragments such as coral, bivalve, spine of cidarid echinoid, ostracoda and bryozoa.

The middle part (9 m) mainly consist of mudstone, intercalating of thin fine sandstone. Several block limestones, 3 to 4 m in diameter, are contained in the mudstone. These blocks are strongly alterated and recrystallined by the thermal influences.

The upper part (16 m) begin with rudstone facies and change to micritic facies upward drastically. In rudstone facies, fossils fragment such as coral gastropods, rudist, spine of cidarid echinoid, are well sorted and have almost same size, 2 to 6 centimeters in diameter. The micritic facies are well bedded, and stylolitic texture are observed.

The uppermost part (3 m) composed from alternating beds of sandy limestone and calcareous mudstone. Small fossils fragments are observed both sandy limestone and calcareous mudstone.

4. Uppermost Sandstone and Mudstone Member (over 80 m)

Because of only few outcrop are exposed, the detail stratigraphy of the member are still ambiguous. In the range that can be observed, the member consist from alternating beds of sandstone and mudstone, and are well bedded in several centimeters to several ten centimeters order.

In the northern part of Murotsu area, it is observed that thick conglomerate are overlain the Uppermost Sandstone and Mudstone Member conformably (Fig. 7). The conglomerate consist from cobbles and pebbles sandstone and chert mainly, and is correlated to the basal conglomerate of Lower Wakamiya Formation (Wakino Subgroup) (Hase, 1958).

C. Asa area

The Lower Cretaceous overlying unconformably the Mine Group are classified as follows, and the geological map is shown in Fig. 9.

1. Wakino Subgroup

Hase (1958) divided into two formations in the same way with the Yoshimo-Kikugawa area, but it is very difficult to define two formations.

Basal conglomerate is well exposed in the Yunoto along the Asa river, it consist from ill-sorted, subrounded to subangular cobbles and boulders sandstone and chert.

Main part of the group consist from alternating beds of fine to coarse grained quartzose sandstone and gray to dark gray mudstone.

Thickness of the formation and clastics size are decreasing to the Eastward, and it doesn't clearly observed.

2. Shimonoseki Subgroup

a. Shiohama Formation

This formation is composed from alternating beds of granule to pebble size conglomerate and reddish mudstone, intercalating fine to medium grained sandstone.

b. Kitahikoshima Formation

This formation subdivided into three facies lithologically.

Basal part of the formation characterized dacitic to rhyolitic tuffaceous sandstone, containing granule and small pebbles of chart and sandstone.

Main part consist from hornblende-andesite lavas and pyroclastic rocks, strongly alterated generally.

Andesitic sediments change to rhyolitic in the upper part, and locally alternating with tuff or tuffaceous rocks.

c. Sujigahama Formation

This formation consist of alternating beds of medium to fine grained sandstone and granule to small pebble conglomerate, occasionally intercalating of reddish to purple mudstone.

3. Shunan Group

The Shunan group covers the Kitahikoshima and Sujigahama formations clino-unconformity. It consists mainly of andesitic to dacitic lavas and pyroclastic rocks and of rhyodacitic to rhyolitic lavas and phyroclastic rocks, and small amount of tuffaceous sandstone and mudstone are intercalated.

D. Toyota area

The geological map is shown in Fig. 10.

1. Dai Group

The Dai Group belongs to the Nagato Tectonic Zone, and is characterized by weak metamorphosed black to dark gray mudstone, containing various size of chert and tuffaceous blocks.

2. Mine Group

This group consist from coarse to fine grained arkose sandstone, intercalating of well rounded cobbles and pebbles conglomerate. It is so massive that the bedding is not clearly observed.

3. Wakino Subgroup

The Wakino Subgroup in this area characterized by the predominance of tuffaceous sandstone. Fining upward from granule conglomerate or coarse grained tuffaceous sandstone to dark reddish mudstone are repeated in several meters order.

4. Other intrusive rocks

Two types of igneous rock are observed in this area as intrusive dyke. Dacitic dyke is intruded along the tectonical boundary both of the Dai and Mine Groups, and of the Mine Group and the Wakino Subgroup, and is so alterated that details are hardly observed generally. The other is rhyolitic one which intruded into the Wakino Subgroup, almost NS trending.

IV. Provenance Analysis

A. Composition of Conglomerate

Combination of clasts components in conglomerates are shown in Table 1. Based on the table, Jurassic to Lower Cretaceous formations divided into three periods.

- The Toyora and Kiyosue period, is characterized by various types of clastics, e.g., schists, plutonics and orthoquartzite, etc.
- The Yoshimo to Wakino period, is characterized by relatively simple combination such as sandstone and chert.
- The Shimonoseki period, is characterized by containing of volcanics.

Compositional variation of conglomerate in the Kanmon Group are shown in Fig. 11. Sample of conglomerate are gathered from the Kanmon Group (one locality in the Lower Wakamiya Formation, one locality in the Shiohama Formation and four localities in the Sujigahama Formation) at six localities. 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. Chert gravels are small than sandstone's one, 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 pebbles of andesitic rock.

3. Sujigahama Formation

The conglomerate of the Sujigahama Formation consist of rounded to subrounded pebbles and cobbles of chert, sandstone and volcanics. Large number of volcanics are included in the lower part of the formation, but it tend to decrease for upward, in contrast to chert gravels.

B. Composition of Sandstone

For the provenance analysis of the sediments, modal analysis of sandstone constituent minerals grains and rock fragments has been made. In this study, examination sample were collected from the Toyora, Toyonishi and Kanmon Groups, limited to medium to coarse sandstone. The samples are 4 from the Nishinakayama Formation, 3 from the Utano Formation, 7 from the Kiyosue Formation, 8 from the Yoshimo Formation, 6 from the Lower Wakamiya Formation, 6 from the Upper Wakamiya Formation, 6 from the Shiohama Formation and 12 from the Sujigahama Formation. 1,000 points are examined in each section based on Gazzi-Dickinson point-counting method (Ingersoll et al., 1984; Kumon et al, 1992) and analytical data are shown in Fig. 12 and Fig. 13.

The major constituents of sandstone are classified into monocrystalline quartz, polycrystalline quartz, potash feldspar, plagioclase, rock fragments and matrix. Rock fragments are composed from chert, mudstone, sandstone, slate, schist, plutonic rocks and volcanic rocks.

Fig. 14 and Fig. 15 are Q-F-L and Qm-F-Lt ternary diagram 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 + polycrystalline quartz grains, F = feldspar grains, L = rock fragments, and 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 further subdivided respectively.

1. Toyora Group

The Nishinakayama and Utano Formations are not so different at a point of sandstone composition. They are dominant in monocrystalline and polycrystalline quartz grain, and potash grain are very few. Rock fragments consist from mudstone mainly, and slate and schist fragments also contained. Some particles of plagioclase porphyroblasts are found in the Nishinakayama Formation. In the Dickinson diagram, points are plotted from quartzose recycled to transitional recycled areas in category of Recycled orogen (Fig. 14. A).

2. Kiyosue Formation

The sandstone of the Kiyosue Formation are dominant in monocrystalline and polycrystalline quartz and potash feldspar grain, and plagioclase grains are very few. Rock fragments are almost composed of chert fragments. In the Dickinson diagram, points are plotted in quartzose recycled to transitional recycled area in category of Recycled orogen (Fig. 14. B).

3. Yoshimo Formation

The sandstone of the Yoshimo Formation sandstone are almost consist of monocrystalline and polycrystalline quartz, and rock fragments are rarely contained. In the Dickinson diagram, points are plotted from quartzose recycled in category of Recycled orogen to craton interior in category of Continental block (Fig. 14. C), and it became clear that sandstone of the formation are very matured one.

4. Wakino Subgroup

The sandstone of the Wakino Subgroup characterized by a predominance of lithic fragments which mainly consist of sandstone and chert, and volcanics fragments are rarely contained. In the Dickinson diagram, points are plotted into two different areas, quartzose recycled and lithic recycled in category of Recycled orogen (Fig. 15. A). It suggests that the sandstone of the Wakino Subgroup is derived from two different provenances.

5. Shimonoseki Subgroup

The sandstone of the Shimonoseki Subgroup characterized by volcanics rock fragments. The less monocrystalline quartz grain are contained compared with the other formations, in contrast to many feldspar grain are contained. In the Dickinson diagram, points are plotted all of the areas (Fig. 15. B). It indicates that major volcanic activities were started in this period.

C. Diachronous changes of provenance

Compositional variation of rock fragments (Fig. 13) indicate provenance areas, typically. Judging from features described above, following provenances change are reconstructed.

1. Toyora Group

The provenance of the group is the Nagato Tectonic Zone constituent rocks. It based on the fact that schists are supplied for gravels in conglomerate and rock fragments of sandstone, as well as, I find out the plagioclase porphyroblasts in sandstone of the Nishinakayama Formation. And 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 grain are so few.

2. Kiyosue Formation

The provenance of the group is the Triassic Mine and Atsu Groups. It based on the fact that granitic clasts are contained abundantly in conglomerates, and many potash feldspar are contained in the sandstone.

3. Yoshimo Formation

Judging from the sandstone are mainly composed of fine grained monocrystalline quartz, and other minerals and lithic fragments are rarely contained, as well as conglomerate containing large clastics are not developed, highly matured sediments were derived from continental area which assumed in the northwest direction of the basin, and was transported for long distance.

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. It based on the fact that large size of limestone clasts are observed in basal facies. It may derived from the Akiyoshi Limestone Group, and also cobble size of chert clasts are derived from the Ota and Tsunemori Groups.

The matured quartzose sandstone were derived from continental area in the same way of the Yoshimo Formation.

5. Shimonoseki Subgroup

Based on the voluminous volcanics are contained in Shimonoseki Subgroup, and it contained in the lower part of the Sujigahama formation mostly, and tend to decreased into upward, main provenance of the Subgroup is andesitic to dacitic lavas and phyroclastic rocks in the same period.

To summarize these data, almost sediments were derived from the Akiyoshi Terrane, eastward area of the Nagato Tectonic Zone. And continental provenance such as Hida Terrane may exposed in the northwest direction of the basin.

V. Geometry of Sedimentary Basin

A. Geometry of the Kanmon Basin

The columnar sections of the Toyonishi and Kanmon Groups in the Yoshimo-Kikugawa area are shown in Figure 16, in which the thickness change of the formation in the east is compared to that in the west. From this figure, it is clear that the Upper Mesozoic formations are thicker in east of the area, and decreased toward the west.

As described in previous section, 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 Figure 17, 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 the southeast.

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

Provenances of the Wakino Subgroup are probably derived from the Sangun metamorphic rocks in north 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.

B. Sedimentary Basins in East Asia

Distribution of the Lower Cretaceous sedimentary basins from East China Sea to Southwest Japan is shown in Fig. 18. It is recognized that large-scale NNE-SSW trending strike-slip faults are developed parallel to each other, and basins are distributed in close relation to these major faults.

Most fundamental are three tectonic units arranged parallel with the general trend of NNE-SSW. 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 accumulated 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 (Fig. 19 and 20).

A new paradigm for understanding these tectonical evolution has recently 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), thus, superplume volcanic events during the Cretaceous played an important role in controlling the Cretaceous environments in East Asia (Okada, 1995).

VI. Sedimentary Facies Analysis

A. Facies analysis

Sediment which deposited in special environments have distinct characteristics, i.e., texture, sedimentary structures, mineralogical and chemical composition, preserved fauna and flora, trace fossils, etc. The body of rocks characterized by them is called facies (Walker, R. G., 1992). Individual facies types 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). Facies observed localities are shown in Fig. 21 and Fig. 22. Twenty sedimentary facies are obtained from the study section on the basis of the sedimentary facies analysis (Table. 2, modified from Miall, 1978).

Facies Gms : matrix supported conglomerate, massive, and doesn't show normal grading. Size of clastics is widely variable from mm to several meters in diameter. In many case, matrix are composed from red to dark colored mudstone, siltstone, sandy siltstone. This facies is interpreted as a debris flow deposits at the proximal to mid fan.

Facies Gm : clast-supported conglomerate, massive or crudely stratified horizontally. This facie normally has an erosive base and shows imbrication of gravel occasionally. Mainly consist from pebble to boulder size clastics, and thickness of a single bed ranges 1.5 to 4 m. This facies is interpreted as a longitudinal bars and channel floor of the braided river, or lag deposit in a channel of meandering river.

Facies Gp : planar cross-bedded clast-supported conglomerate. The thickness of a set of the cross-bedding ranges from 10 to 50 centimeters. This facie normally has an erosive base. Clastics size is generally very coarse sandstone to cobble gravel. This facies is interpreted as a longitudinal bars.

Facies St : solitary or grouped trough cross bedded sandstone, pebbly gravels are intercalating frequently. The thickness of a set of the cross-bedding ranges from 10 to

40 centimeters. Grain size is generally small pebble gravel to medium sandstone. This facies is interpreted as a sand bars, and rough cross-bedding in the sandstone results from the formation of sinuous-crested dunes.

Facies Sp : solitary or grouped planer cross bedded sandstone, pebbly gravels are intercalating frequently. The thickness of a set of the cross-bedding ranges from 10 to 40 centimeters. Grain size is generally small pebble gravel to medium sandstone. This facies is interpreted as a linguoid, transverse bars, sand waves in a lower flow regime.

Facies Sh : horizontally laminated sandstone. Mainly consist from very fine to very coarse sandstone. It forms beds and their thickness ranges from 1 to 3 meters. This facies is interpreted as a planer bed flow in the upper flow regime.

Facies Sc : massive or normal grading sandstone. Mainly consist from very fine to very coarse sandstone. The thickness of a bed ranges from 20 centimeters to several meters. The beds have flat bases, which are often erosive. Bioturbated texture are observed frequently. This facies is developed usually in accompaniment with facies Fl. These features are very similar to those of crevasse splay deposits of the Cercadillo Sandstone and Siltstone Formation in central Spain (Garcia-Gil, 1993), and this facies is interpreted as crevasse splay deposits at the floodplain of the meandering river.

Facies Sw : massive or normal grading sandstone, containing brackish molluscs frequently. Bioturbated texture are observed frequently, and is developed usually in accompaniment with facies Fb. The thickness of a bed ranges from 20 centimeters to several meters. The beds have flat bases, which are often erosive. This facies is interpreted as a wash over fan or flood tidal delta at the lagoonal environment.

Facies Fb : massive or parallel laminated fine sediments, containing brackish molluscs frequently. The thickness of a bed ranges from 10 centimeters to 1 meters. This facies is interpreted as a lagoonal deposit.

Facies Fl : dark colored fine sediments. fine lamination, small ripples are observed. The thickness of a bed ranges from 10 centimeters to several meters. This facies can be regarded as a floodplain deposit.

Facies Fr : red to reddish purple colored fine sediments. fine lamination, small ripples and bioturbated texture are observed. The thickness of a bed ranges from 10 centimeters to several meters. This facies can be regarded as a floodplain deposit that deposited under arid and high temperature climate.

Facies Fc : massive bluish to reddish mudstone. The thickness of a bed is about 10 centimeters to 1 meter. This facies yield some calcretes. The calcretes appear as nodular to layered formation arranged parallel to the bedding. Diameter of the nodules are 2 mm to 2 centimeters, and thickness of layer containing calcretes is 2 to 16 centimeters. This facies is interpreted as a soil with chemical precipitation.

B. Depositional environment

Based on these facies analysis, it is enable to reconstruct a five types of typical depositional model (Fig. 23) in the Toyonishi and Kanmon Groups at the Yoshimo-Kikugawa area, independent of the lithological formation boundary. These depositional environments are described as follows.

1. Lagoon

Lagoonal environment formed at the river mouth, and consist from 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 are wholly or partially, and tidal channel that cut through the barrier and connect the lagoons to the open sea. In case of the microtidal environment (0-2 m tidal range), barrier islands tends 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 (Fb) are deposited in normal weather climate, and washover sandstone (Fw) are formed at storm climate. This environment is formed when the relative sea level is high.

2. Lacustrine

When relative sea level is not so high, lakes occur in areas of crustal subsidence, and they are not inundated by the sea water. Because of many deltas are formed at the point where a river enters an large body of water, lacustrine sediments are characterized both lake sediments and delta's one. The sediment in a delta is normally derived directly from the river that feed it. Coleman and Wright (1975) presented a series of composite vertical facies successions through the prodelta, delta front and delta plain environment. Delta produce a thick coarsening-upward facies succession, and it is considered that the thickness of the succession almost equal in depth of a lake. Delta plain to delta front facies show the predominance of deposition by fluvial processes, on the other hand, prodelta facies characterized by the lacustrine deposits.

3. Meandering River

Meandering streams typically occupy a position downstream from braided river and upstream from deltas in the fluvial system. They occur in coastal plain regions, where they flow more or less perpendicular to the coast, and are characterized by single channels.

Meandering streams accumulate two distinct sediment types within the channels itself: channel lag deposits, which are located in the channel floor, and point bars, which form on the inside of the meander loops. The normal grading unit of this type sediment is relatively more thick compare to braided rivers one. When extreme discharge events are caused, a stream overtop 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 (Sc, Fl) deposits and oxbow lake. Calcretes containing red shale (Fc) is typical sequence of the overbank deposit in arid climate.

4. Braided River

Braided stream are developed on steeper slopes than meandering one, 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 beds formed under decreasing velocity are superimposed

(2) lateral accretion as side or point bars develop

(3) channel aggradation as a channel fills because of 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

Fan require an area of high relief and an adjacent lowlying area for sediment accumulation. In many case, fan are related to the tectonic activity because of the need for high relief. Fan divided into proximal, middle and distal fan. Channel patterns are characterized by several deeply incised channels in the proximal zone. The middle fan contains numerous braided channels with numerous longitudinal bars separating the channels. Distal fan areas contain braided channels patterns similar to those of the middle fan, but channels are smaller and less dense braiding. Fan sequence consists of debris flow deposits (Gms), stream channel deposit (Gm), sheetflood deposit (Fl) and sieve deposit, and imbrications are observed in gravels. Generally, fan sediments are more gravely and thick than the other environments.

C. Descriptions of each formation

The observation of the facies in the seaside outcrop from Toyonishi and Kanmon Groups described as follows.

1. Toyonishi Group

a. Kiyosue Formation

Along the southern part of the Yoshimo coast, the coarse-grained sandstone intercalating black mudstone are exposed. It consists of point bar deposit of the meandering river that begins with channel lag deposits of pebble size gravels and grading normally to shale about ten meters thick (Fig. 24. Ky01).

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, and it is the lower part of the Yoshimo Formation. It consist of deltaic facies in lower, and lagoon facies in main part (Fig. 24. Yo01).

2. Wakino Subgroup

a. Lower Wakamiya Formation

Along the northern part of the Ogawara coast, the conglomerate intercalating sandstone are exposed. It is a basement facies of the Lower Wakamiya formation, and consists of braided river sequence (Fig. 25). It is composed from channel deposit and abandon channel deposit of the upper fan.

b. Upper Wakamiya Formation

Along the northern part of the Toyano-hana, the alternating bed of fine-grained sandstone and black mudstone are exposed. It is a middle lithofacies of the formation, and consists of deltaic and lacustrine facies (Fig. 26). The coarsening-upward sequence is repeated four times.

Along the northern part of the Ajirono-hana, the alternating bed of red shale and fine-grained greenish gray sandstone of the upper most Bishanohana Formation are exposed. It consists of the floodplain deposit and crevasse splay deposits of the meandering river (Fig. 27. 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. It is a basement facies (Fig. 27. Si01) and upper most part (Fig. 27. Si02) of the formation, and it is mainly composed from meandering rivers deposits.

b. Sujigahama Formation

From Kushimoto to Fukue coast, the Sujigahama Formation is exposed. It is composed from combined sequences of meandering river, braided river and fan (Fig. 28 to 31).

D. Developing process of sedimentary basin

Based on the facies analysis, changes of the depositional environments of these Upper Mesozoic can be made as shown in Figure 32. It is considered that the depositional environment discontinued by the movement of the sedimentary basin reflect to the boundary fault activity. On the other hand, when tilting movement of the basin have been stopped or moved gently, depositional environment was continuously changed according to the dissection process of the provenances, consequently, derived sediments become decrease and fine-grained. Unconformity surface are formed in the point of depositional environment discontinued. It is the reason why the growth speed of the boundary faults are so high that depositional environments are suddenly changed, and clastics become increase and coarse-grained by uplifting movement of the provenance areas.

The changes of the depositional environment also suggests that the sedimentary basin uplifted on the whole. Depositional environments that begin with neritic of the Toyora Group is taken over to the brackish of the Toyonishi Group, and lacustrine facies of the Wakino Subgroup change to fluvial conglomerate of the Shimonoseki Subgroup, finally. It means that emerge movement was dominated in this area from Jurassic to Lower Cretaceous.

In the upper Sujigahama Formation, sedimentary basin is emerged mostly, and sedimentation is ended. It is considered that the total changes of the sedimentary environment corresponded to the pre-stage activity prior to the igneous activity of the Late Cretaceous.

VII. Geologic Structure

A. Descriptions of local geologic structure

1. Yoshimo-Kikuaga area

Geological profiles of the Yoshimo-Kikugawa area are shown in Figure 33. The structural contour diagram based on the unconformity surface of the Wakino Subgroup is shown in Figure 34. To use structural contour diagram, it is possible to understand the geologic structure excluding geographical influences.

The Toyora, Toyonishi and Kanmon Groups are structurally similar to each other, and form NEE-SWW trending asymmetric synclines and anticlines repeated number of times. The structure which consist from closed shape anticline and syncline of relatively open shape in the viewpoint of interlimb angle are called as ridge-like shape fold. Generally, south side of the anticline axis is more steep than north. Plunges of fold axis are dipping westward in the eastern part of the Yoshimo-Kikugawa area, and are almost horizontal in the central and western part. The intensity of the folding varies from east to west. In the eastern part of the area, folds have considerable intense and more closed shape, on the other hand, their are more gently folded in the western part.

The above mentioned folds are cut by numerous faults chiefly of NNE-SSW and NW-SE trends. Judging from the movements of the main anticline axis, the NNE - SSW trending faults have left-lateral strike-slip movement and NW-SE faults show opposite movement. Left-lateral movements are predominant in this area.

Based on these faults have N-S compressional displacements, and might be formed at the same time, it is inferred that these faults are conjugated fault system which are formed under N-S compressional stress.

Yoshidomi (1995) pointed out that folds and faults were formed simultaneously, because of displacement length of anticline axis and syncline axis by NNE - SSW trending fault are different with each other.

According to the Ogushi and Ozuki granites are not deformed, it is considered that the geological structure such as folds and faults are formed prior to granites emplacement.

2. Asa area

The Kanmon Group overlies the Mine Group with a slightly oblique unconformity, and have gently north dipping structure. Because of the volcanic rocks of Shunan Group are almost covered unconformably, it is hardly to know the north boundary of the sedimentary basin. It is supposed to be a steep boundary which consist from a boundary fault.

In this study, it became clear that NNE - SSW trending en-echelon shape left-lateral strike-slip faults are well developed in the western part of asa area. The Mine and Kanmon Groups are deformed by these faults, but the Shunan Group covered these structure unconformably. It is considered that faults are formed post-Kitahikoshima age and prior to the igneous activity of the Shunan ages.

3. Toyota area

In Toyota area, it is observed that zonal distribution of the Dai, Mine and Kanmon Groups trending NE-SW. This zonal distribution constitutes part of southwestern Dai area of the Nagato Tectonic Zone, and includes many sub parallel faults and narrow dacitic intrusive rocks running NE-SW. These groups are contacted with each other by fault. Light gray to yellow colored strongly alterated dacitic rock is intruded between the Mine and Kanmon Groups. NNE-SSE trending fault cut these zonal distribution, and fracture zone which have several meters width are well observed along the fault. This fault is parallel to well known the Shibuki Fault (Quaternary fault) that was estimated from the geographical lineament structure.

N-S trending left-lateral geographical displacement are observed along the dacitic intrusive rock of the west part of the area, but it is hardly to indicate the geological evidence.

B. Summary of Geologic Structure

Many folds and faults are observed in the Upper Mesozoic formations. Major geologic structures in these formations are shown in Fig. 35. Geologic structures are different on both sides of the Toyota Tectonic Line (indicated as a red broken line in Figure 35) newly defined in this study.

It is supposed that the Toyota Tectonic Line extends to the Kokura-Tagawa Fault featured by left-lateral strike-slip movement in north Kyushu.

The western area of the tectonic line has E-W trending fold axises and are parallely faulted in the south part of the Toyota Tectonic Line. On the other hand, the east area is dominated NE-SW trending fold axises, and faults are not so developed. The NE-SW trending fold axises in the east area resemble the folding structures in the Triassic Mine Group.

These fold axises are oriented with an angle of about 45° to the tectonic line in the west area, but they are almost parallel to the tectonic line in the east area.

The boundary between the Paleozoic formations and the Lower Cretaceous formations is consist from unconformity to complicated form (indicated as green lines in Figure 35) in the northern Yamaguchi Prefecture and Kyushu. In contrast, linear faults take a important part as the boundary in the southwestern Yamaguchi Prefecture.

Yoshidomi (1995) pointed out the possibility that these structure was formed as a secondary shear structures of the Riedel Shares system.

Based on these observed geologic structures, it is possible to make a deformation model of left-lateral strike-slip movement of the Toyota Tectonic Line as shown in Fig. 36.

The Toyota Tectonic Line is steeply oriented and featured mainly by left-lateral movements accompanied with dip-slip. It is considered that the faults NNE-SSW trending both in the Yoshimo-Kikugawa and in Asa areas are may be regarded as sub-parallel set of the Toyota Tectonic Line. Similarly, N-S compressional conjugate faults are the second structures in an angle of about 60° to the main structure.

It is well known that the movement of an en-echelon fault causes strain between two faults, and the development of compression are oblique to the main fault. The compression are generally released by the formation of folds and thrusts. The initially formed fold traces and thrust strike directions are oriented about 45° to the main fault trace.

It is considered that folding structures of the west area were formed in this way.

This left-lateral strike-slip model can also explain the differences between the north and south part of the Nagato Tectonic Zone (Fig 37). Misumi and Dai areas in the north part of the Nagato Tectonic Zone constitute a tectonic melanges formed from basin formational dip-slip movement, and are unconformably covered by the Lower Cretaceous formations. On the other hand, Nishiichi, Toyoga-take and Ozuki areas in the south part of the Nagato Tectonic Zone were exposed by strike-slip movement of the Toyota Tectonic Line. That is why the Upper Mesozoic formations of the southern Yamaguchi Prefecture contact the Paleozoic formations only by faults.

Zonal distribution of the Sangun-Renge Belt, Akiyoshi Terrane and Suo Terrane trending NE-SW also were cut by the Toyota Tectonic Line, and each boundary moved to the south.

The depositional age of Shimonoseki Subgroup is estimated to be younger than 100 Ma.

The the Ogushi Granite (90.7 Ma: Suzuki, 1986) and the Ozuki Granite (94 Ma: Kawano and Ueda, 1966) are intruded discordantly into the Lower Cretaceous sediments, and are not deformed. Similarly, en-echelon shape left-lateral strike-slip faults of the Asa area are unconformably overlain by the Shunan Group (94.2 to 85.2 Ma: Murakami, 1985).

Based on these data, the significant deformation must have occurred in a the short interval of 6 Ma.

VIII. Discussion

A. Definition of the Murotsu Formation (new name)

In recent year, Yoshidomi and Inoue (2001) reported corals, nerineid gastropods, bivalves and cidarid echinoids from limestones regarded as lacustrine sediments belonging to the Wakino Subgroup (Lower part of the Kanmon Group), and suggested that these limestones are marine facies of the Toyonishi Group and re-examination of the stratigraphy and depositional environment of the Toyonishi Group is needed.

They divided formations exposed in the sea-side of the Murotsu area into four members based on lithological properties, Lower Mudstone Member, Middle Sandstone and Mudstone Member, Upper Limestone Member and Uppermost Sandstone and Mudstone Member in ascending order, and suggested that the Uppermost member can be correlate to the Yoshimo formation in conjunction with the occurrence of brackish fauna, i.e. *Eomiodon matsumotoi*, *Isodomella matsumotoi*, *Ostrea* sp., *Tetoria* sp.

Based on the lithological properties of the Lower member (consist from mudstone predominant alternating beds of coaly mudstone and coarse grained arkose sandstone), it is able to correlate with the Kiyosue Formation.

Because of the Toyonishi Group have been divided into two formations basis on the bearing fossils originally, the lower part of plant fossils and the upper part of brackish molluscs (Matsumoto, 1949; Hase, 1958), a new definition is necessary for members containing limestones.

In this study, I newly defined the formation containing limestone (Middle Sandstone and Mudstone Member and Upper Limestone Member) as “Murotsu Formation”, and is considered to be a contemporaneous heterotopic facies of lower part of the Yoshimo Formation.

Plant fossils of the Kiyosue Formation are also 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 and Mikami, 1975b).

It has been pointed out the resemblance of the Yoshimo Formation and the Lower Cretaceous formations in the Outer Zone of Southwest Japan e.g. the Nankai Group of Shikoku district, Kawaguchi Formation and Uminoura Formation of Pre-Sotoizumi Group in Kyushu in conjunction with the occurrence of the brackish fauna (Tashiro et al., 1994).

The fauna of the Murotsu Formation is also comparable to the Torinosu Fauna, which is known as Tethyan type fauna, widely distributed in the Chichibu Belt, Outer Zone of SW Japan, but brackish fauna are not contained in the Torinosu Group.

Close relationship of the Tethyan type brackish fauna and Torinosu Fauna is only observed in the Birafu Formation of the Nankai Group (Morino et al., 1989), and the Kurosaki and Kawaguchi Formations of the Pre-Sotoizumi Group, the Outer Zone of Southwest Japan.

These facts described above indicated that the depositional environments of the earliest Cretaceous are not so different both Inner Zone and Outer Zone of Southwest Japan in conjunction with the occurrence of fauna which closely related to the Tethys Sea, although they become quite different later.

B. Evolution process of the Kanmon Basin

Jurassic to Cretaceous tectonics in East Asia are discussed in many articles (e.g. Xu et al., 1989; Lee and Paik, 1990; Okada, 1995). The purpose of this section is to discuss the tectonics and developing process of the Kanmon Basin with stratigraphy, composition of clastics, sedimentary environments and geological structures. Evolution process of the Kanmon Basin is discussed in many scientists (e.g. Okada, 1991; Seo et al., 1992). They suggests that the Kanmon Basin formed as a strike-slip basin judging from the remarkable lateral changes of the formation thickness and lithological character. But thickness and lithological character can easily varies so that formations of the Kanmon Group are deposited as a fluvial sediments, independently with the sedimentary basin tectonics. In this study, it is clarified that the dip-slip movement were dominated in the boundary fault at least basin formational period, and strike-slip movement occurred in a post-depositional period causing deformational process (folding and faulting). And schematic evolution process of the Kanmon Basin is reconstructed as follows.

1. Late Jurassic to Earliest Cretaceous

The Toyora sea was retreated and the marine environment had come to an end. The Toyonishi Group in the Yoshimo-Kikugawa area was deposited in lagoonal environment of the barrier-island complex (Fig. 38) in restricted extension, covering the eroded the Utano Formation of the Toyora Group with a remarkable basal facies. In the same time, north Kyushu district are situated in a coastal plane, and clastics are transported by meandering river (e.g. point bar, natural levee, crevasse splay and oxbow lake deposit). On the other hand, the north part of the Yoshimo-Kikugawa area being in marine environments, and the Torinosu-type limestones are formed as a fringing reef on the open sea side of the barrier island. Environmental change from the Murotsu Formation to the Yoshimo Formation reflects 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 that progradation of the coastal plane which are characterized by deltaic sediments (Fig. 39). These coastal sediments are overlain by the Wakino Subgroup unconformably.

2. Hauterivian to Barremian

Because of the boundary fault was activated, provenance areas were uplifted in this period, new sedimentary basin appeared in north Kyushu district, and the basin was extensively expanded towards the northeast subsequently. High relief are formed in relation to this tectonic movement. A considerably thick series of braided river sediments, relatively large size immature clastics, was accumulated there (Fig. 40. A). Although fine-grained matured quartzose sandstone derived from the continental area which assumed in the northwest direction of the basin.

According to uplifted provenance area are dissected and become low relief, the quantity and size of derived clastics were 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. 40. B).

The lake will be filled up progressively by a delta formed at rivers mouth, and floodplain, characterized by fine grained red colored overbank deposit, 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.

3. Aptian to Albian

With the beginning of the deposition of the Shiohama Formation the volcanic activities became active, and the activity showed its climax in the Kitahikoshima age. Lava and phyroclastic rocks which relation to volcanic activity accumulated in considerable extension (Fig. 41. A). According to the thickness of the Kitahikoshima Formation is thicker at the North Kyushu and North Yamaguchi Prefecture in contrast to comparatively thinner in Yoshimo-Kikugawa area, center of volcanic activity are assumed to be located in there.

Because of the major volcanic activity ended in the Kitahikoshima age, volcanoclastic are decrease into upward in the Shimonoseki Subgroup. The Upper Sujigahama Formation is characterized by abundant and thick conglomerate with associated red colored mudstone thin layer and lenses (Fig. 41. B). These coarse grained ill-sorted fluvial sediment, consist of chart and sandstone clastics mainly and huge clastic blocks are supplied as debris flow occasionally, are suggested with deposition taking place mainly at the proximal part of fan which developed in arid or semi-arid climates.

4. Cenomanian

The Jurassic to Lower Cretaceous formations was folded and faulted by left-lateral strike-slip movement of the Toyota Tectonic Line (Fig. 42). En-echelon shape left-lateral strike-slip faults of the asa area and thrusting faults of the North Kyushu also formed in relation to this movement. Subsequently, the Shunan Group and Yahata Formation composed of lavas and phyroclastics with a small amount of terrigenous sediments was unconformably sedimented in Asa area and North Kyushu respectively.

IX. Summary and Conclusions

In this paper, the stratigraphy, province analysis, sedimentary environments, developing process of the sedimentary basin and deformation process of the Upper Mesozoic are described. The results are summarized as follows.

1. Shallow marine fossils were discovered from limestones regarded as lacustrine sediments belonging to the Wakino Subgroup. By detailed stratigraphical research, it become clear that the limestones developed in middle part of the Toyonishi Group, and these marine molluscs-bearing members are newly defined by the author as the Murotsu Formation. This neritic formation consist of two members; Lower sandstone and mudstone member and Upper Limestone member, and is considered to be a contemporaneous heterotopic facies of lower part of the Yoshimo Formation.

2. The Murotsu Formation resembles to the Birafu Formation of the Nankai Group (Shikoku) and the Kurosaki and Kawaguchi Formations of the Pre-Sotoizumi Group (Kyushu), the Outer Zone of Southwest Japan, in terms of yielding Tethyan type brackish fauna and Torinosu Fauna closely.

3. The Torinosu-type limestone of the Murotsu Formation indicates that depositional environments are not so different both Inner Zone and Outer Zone of Southwest Japan, and the Tethys Sea expanded to the Murotsu area in the Earliest Cretaceous.

4. Total sediment thickness of the Kanmon Basin attains to 6,000 meters in the Yoshimo-Kikugawa area and clastics were derived mainly from Permian accretionary complexes and Upper Triassic shelf sediments of Akiyoshi Terrane witch distributed on the southeast of the basin. And a small amount of highly matured quartzose sandstone suggest that continental provenance was exposed in northwestern area.

5. 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, same as the sedimentary basins widely distributed in East Asia to Southwest Japan, and bounded by the NE-SW trending Nagato Tectonic Zone with serpentine melange.

6. Provenance analyses suggest that the locations of provenance area and sedimentary basin are not so different from the present, the boundary fault of the Kanmon Basin is dominated by dip-slip movement, and the tectonics of the basin mainly controlled by tilting movement of the half-graven structure.

7. Sedimentary facies analyses suggest that the sequence of Toyonishi and Kanmon Groups are composed from typical five types depositional system, Lagoon, Lacustrine, Meandering river, Braided river and Alluvial fan. The sedimentary basin repeated these environmental changes according to the activities of the boundary fault such as Nagato Tectonic Zone.

8. Upper Mesozoic consist of the marine (Toyora Group) and brackish (Toyonishi Group) sediments in the lower part and changing to lacustrine (Wakino Subgroup) and the fluvial (Shimonoseki Subgroup) in the upper part. It suggest that the basin has an uplift trend as a whole.

9. Geologic structure of the Yoshimo-Kikugawa area characterized by NEE-SWW trending folds and NNE-SSW and NW-SE trending faults. Former show ridge-like shape consist of open shape synclines and closed shape anticlines and are cut by latters. Based on these faults have N-S compressional displacements, and might be formed at the same time, it is inferred that these faults are conjugated fault system

which are formed under N-S compressional stress.

10. In the western Yamaguchi Prefecture, basin formational structures, such as the Nagato Tectonic Zone, were cut by faults newly defined as Toyota Tectonic Line. Features of these deformational structures (folding and faulting) are different on both sides of the tectonic line.

11. Based on the Toyota Tectonic Line extend to the Kokura-Tagawa Fault in north Kyushu and deformation structures of the Upper Mesozoic formations seem to have been formed under NS compressional strains caused by left-lateral strike-slip movement of an en-echelon fault, it is possible to propose a deformation model of left-lateral strike-slip movement of the Toyota Tectonic Line.

12. Because the Kanmon Group contains few clastics derived from sedimentary basin such as red shale, and granitic plutons in the earliest Late Cretaceous age intrude discordantly into the deformed sediments, it seems certain that the intense tectonic deformation occurred during the short interval between the ending of sedimentation and the plutonic emplacement, but must have continuously progressed step by step over a comparatively long period.

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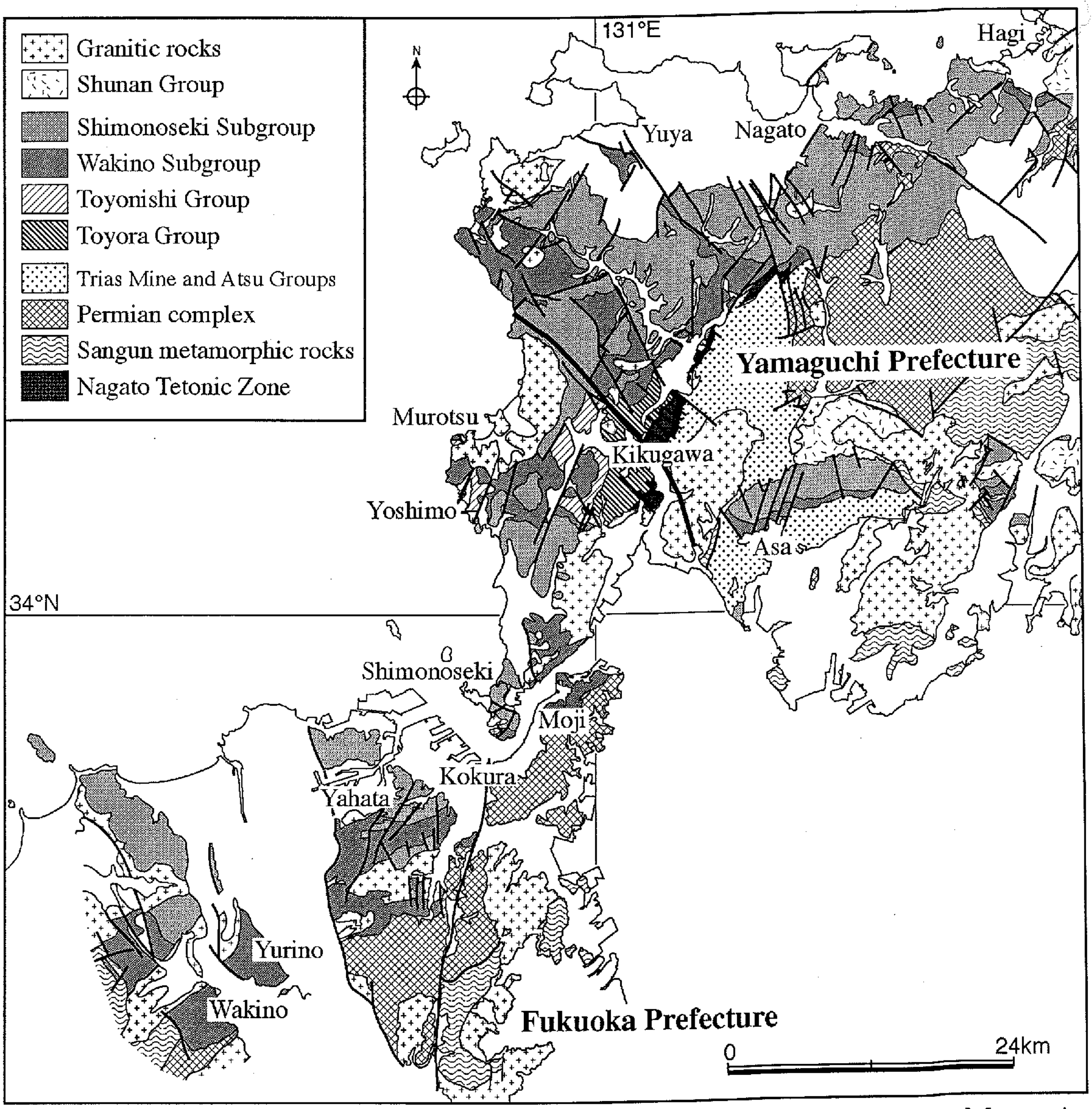


Fig. 1. Compiled geological map of the Upper Mesozoic in Western Yamaguchi and North Kyushu.

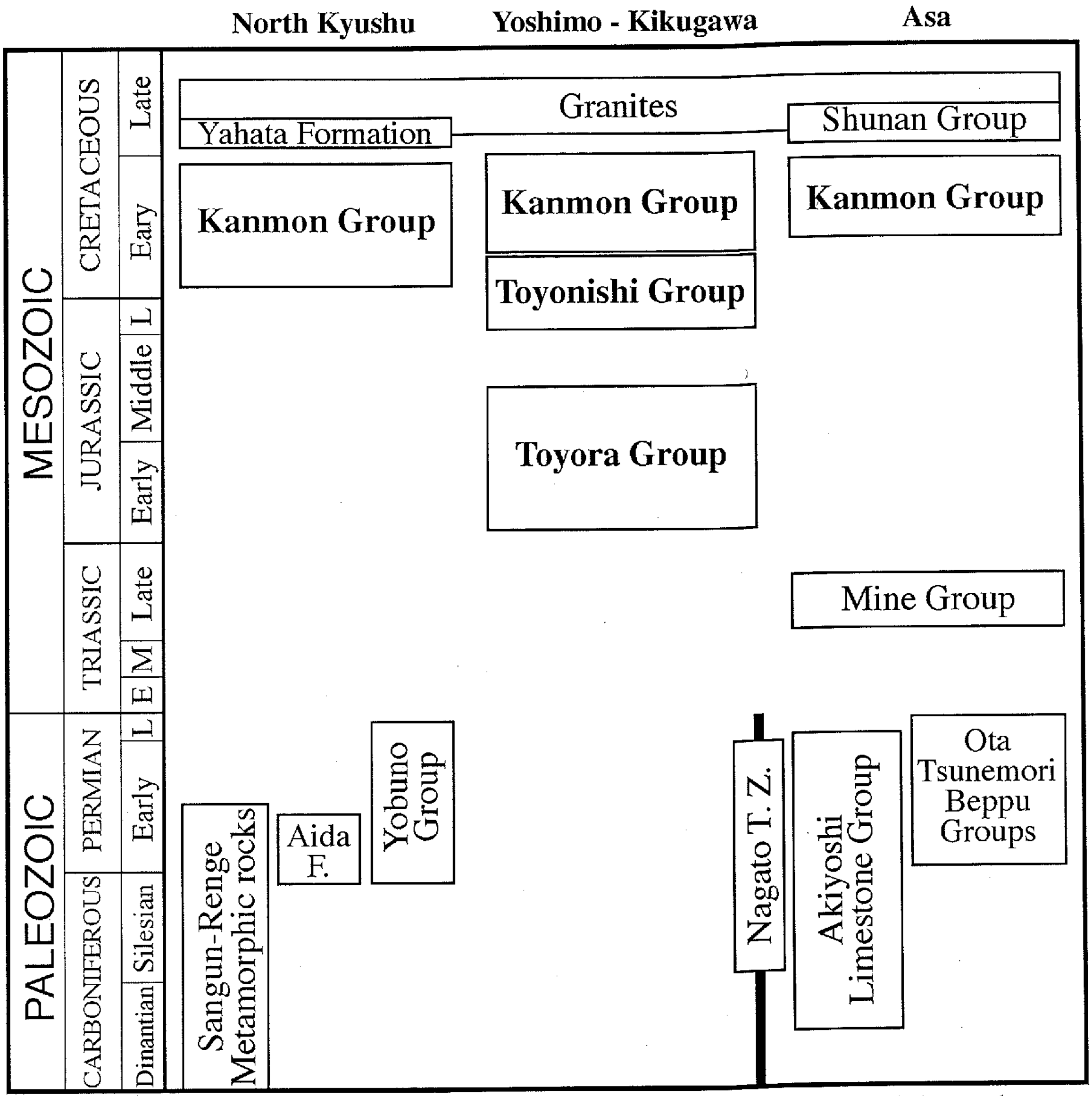


Fig. 2. Geologic units around the study area.

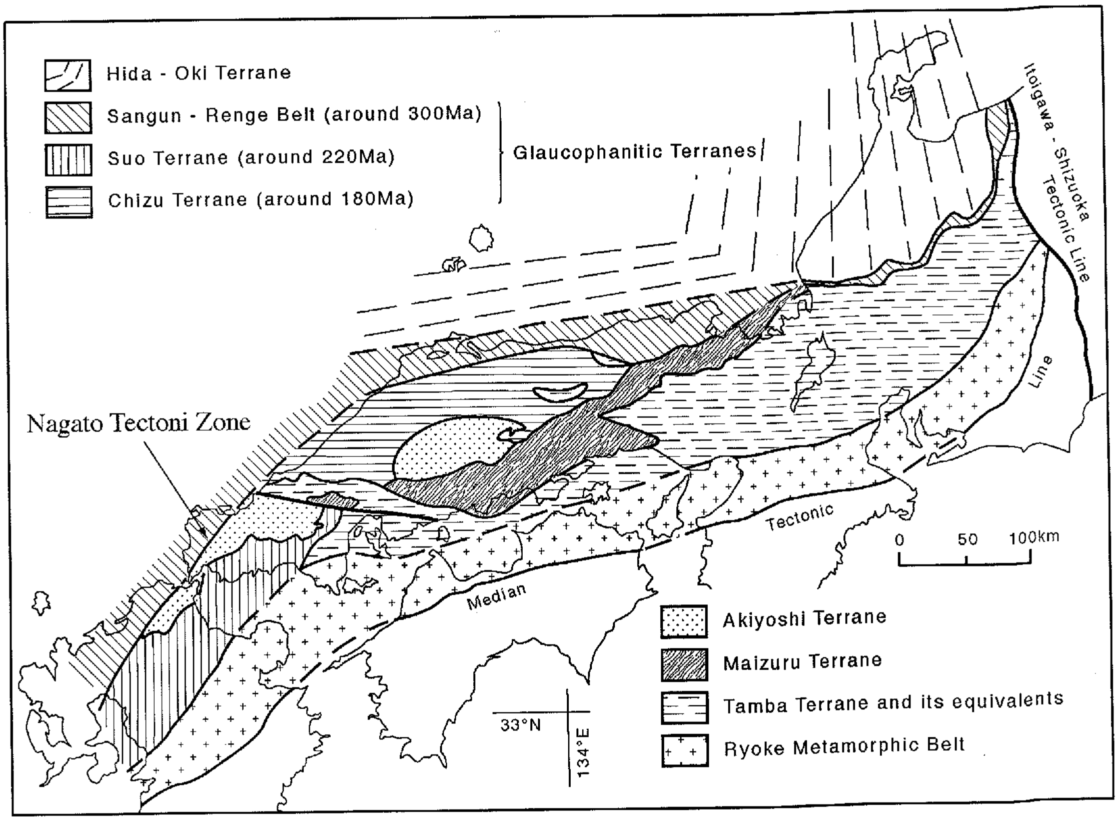


Fig. 3. Tectonic framework in Southwest Japan. (modified from Nishimura, 1989)

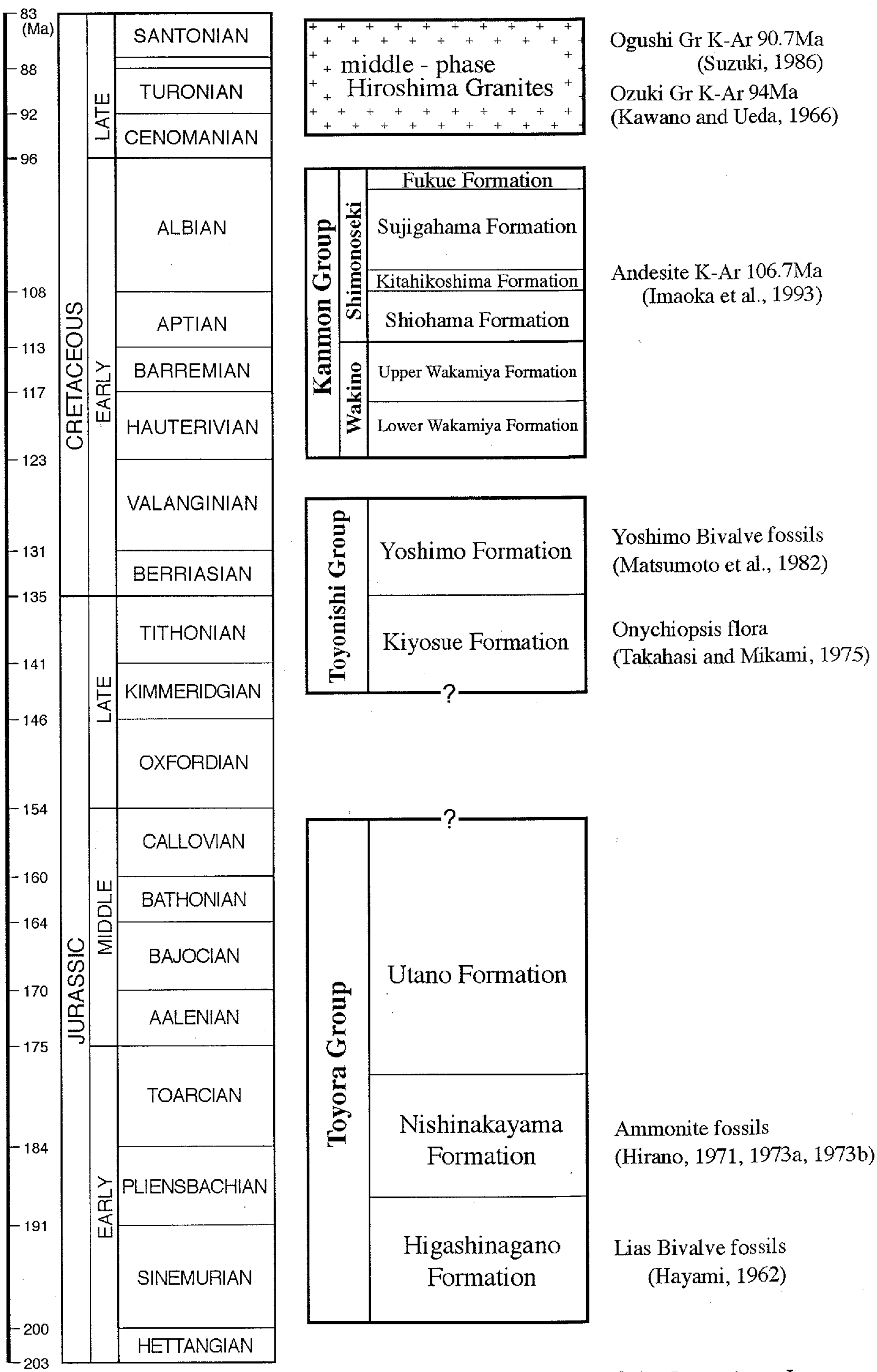


Fig 4. Geological ages of the Jurassic to Lower Cretaceous in Yoshimo - Kikugawa area.

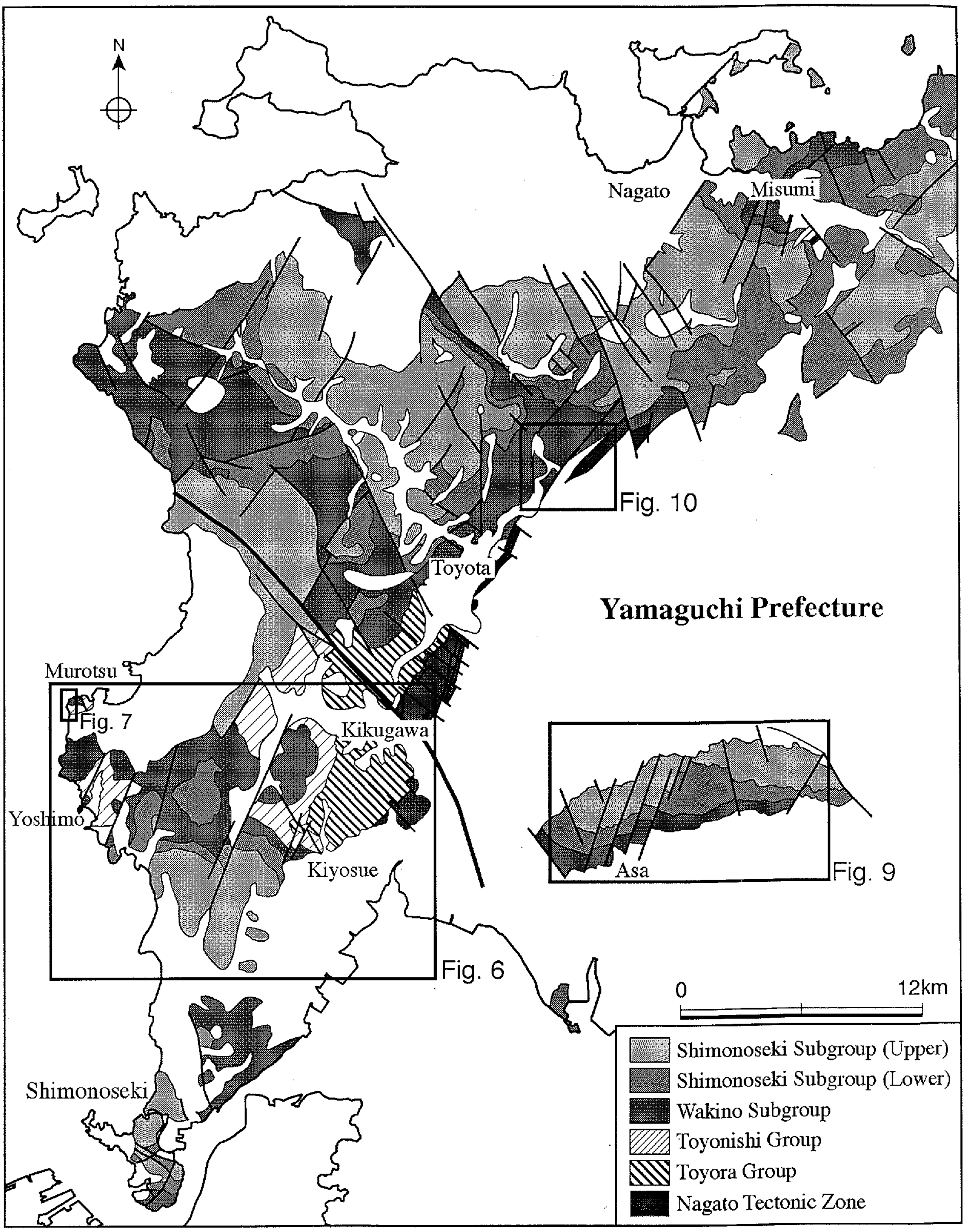


Fig. 5. Distribution of the Jurassic to Lower Cretaceous in Western Yamaguchi Prefecture and locality of the study areas.

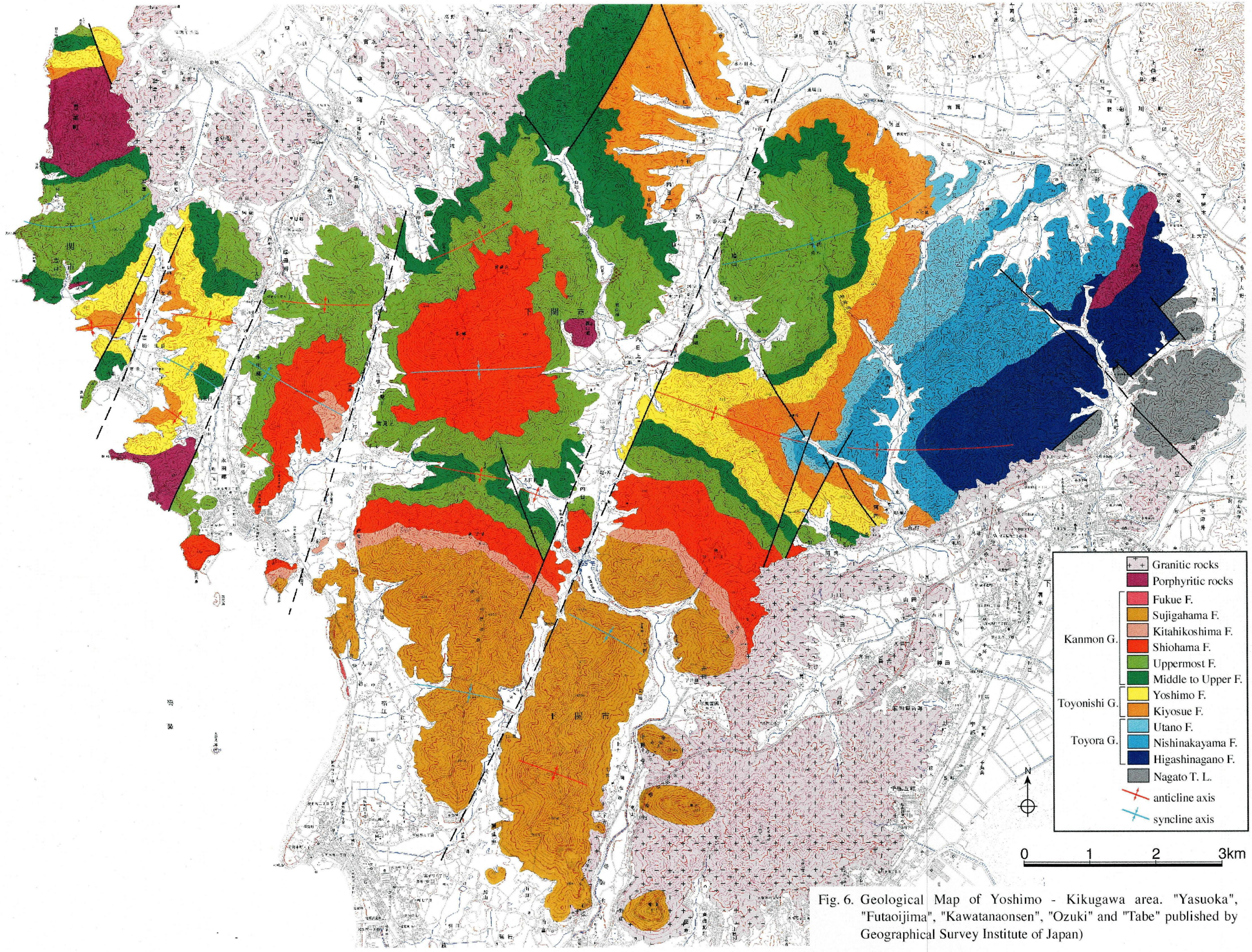


Fig. 6. Geological Map of Yoshimo - Kikugawa area. "Yasuoka", "Futaoijima", "Kawatanaonsen", "Ozuki" and "Tabe" published by Geographical Survey Institute of Japan)

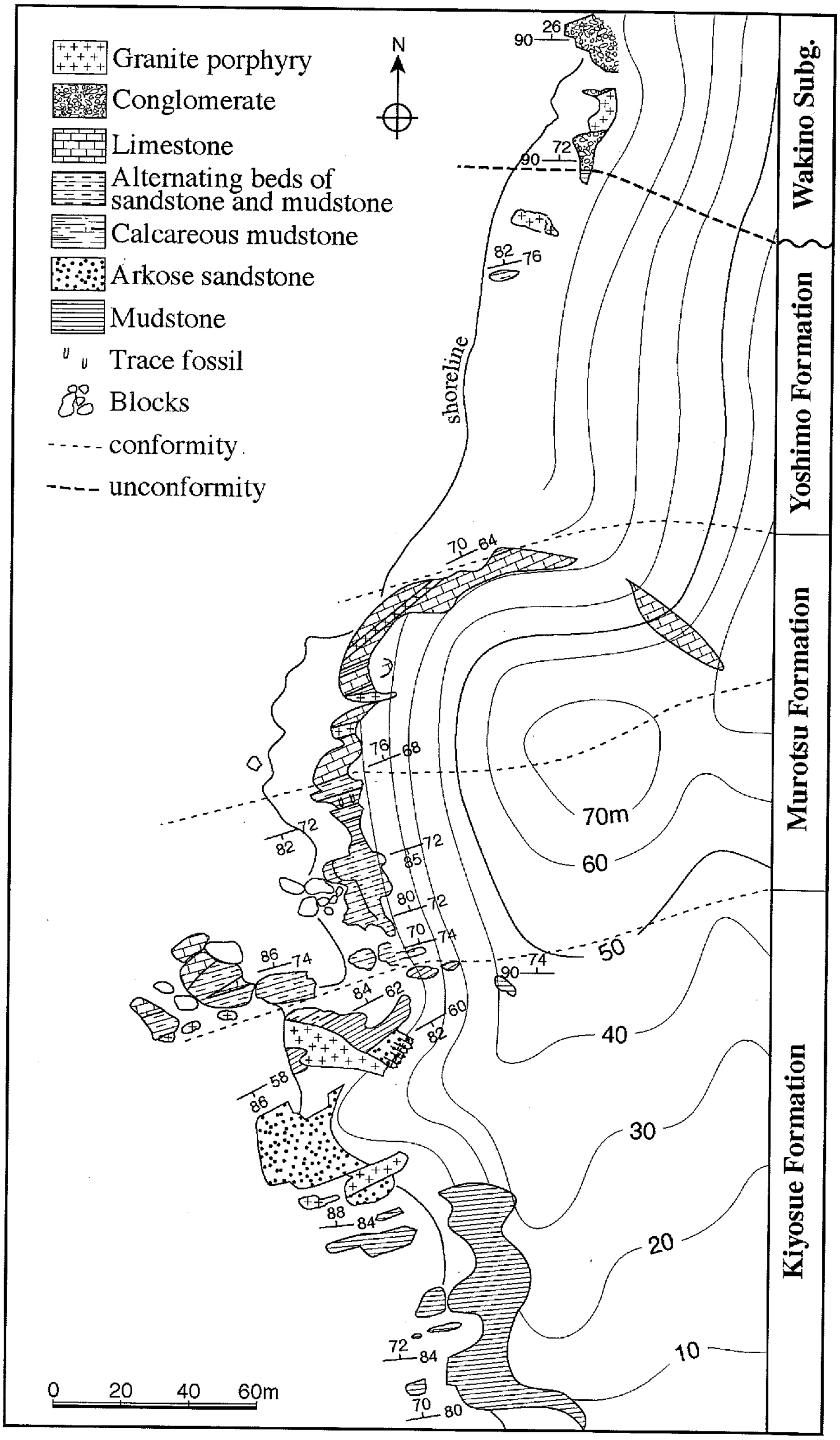


Fig. 7. Route map of the Murotsu area.

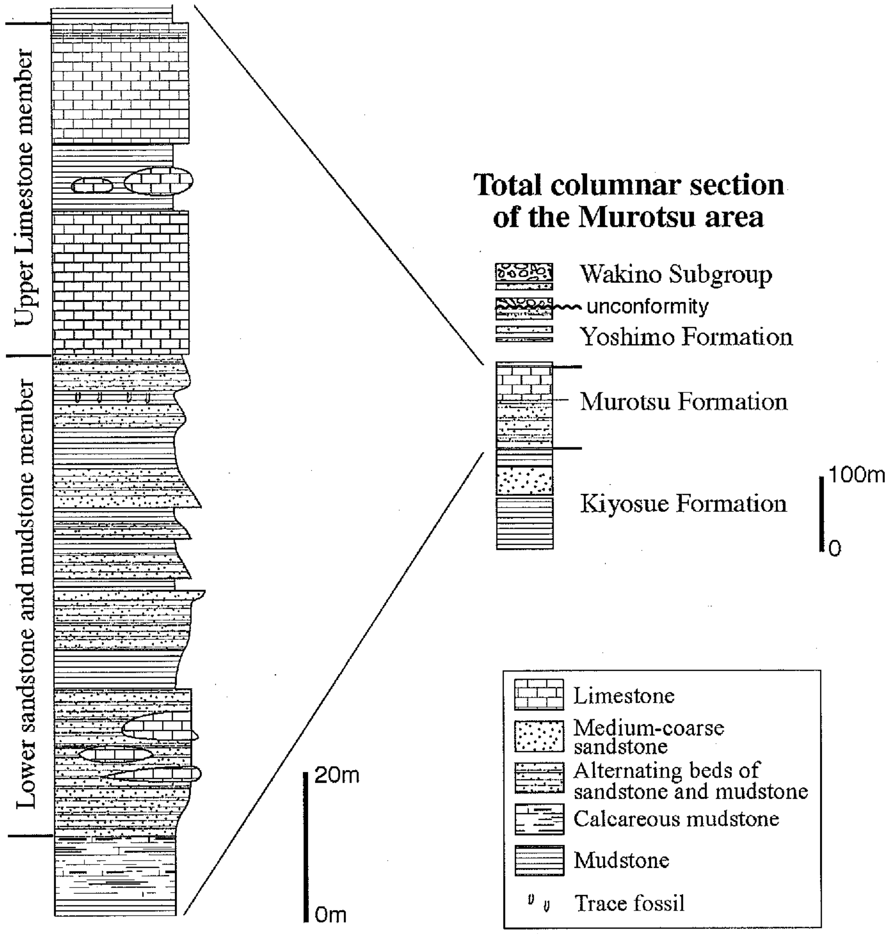


Fig. 8. Columnar section of the Murotsu area.

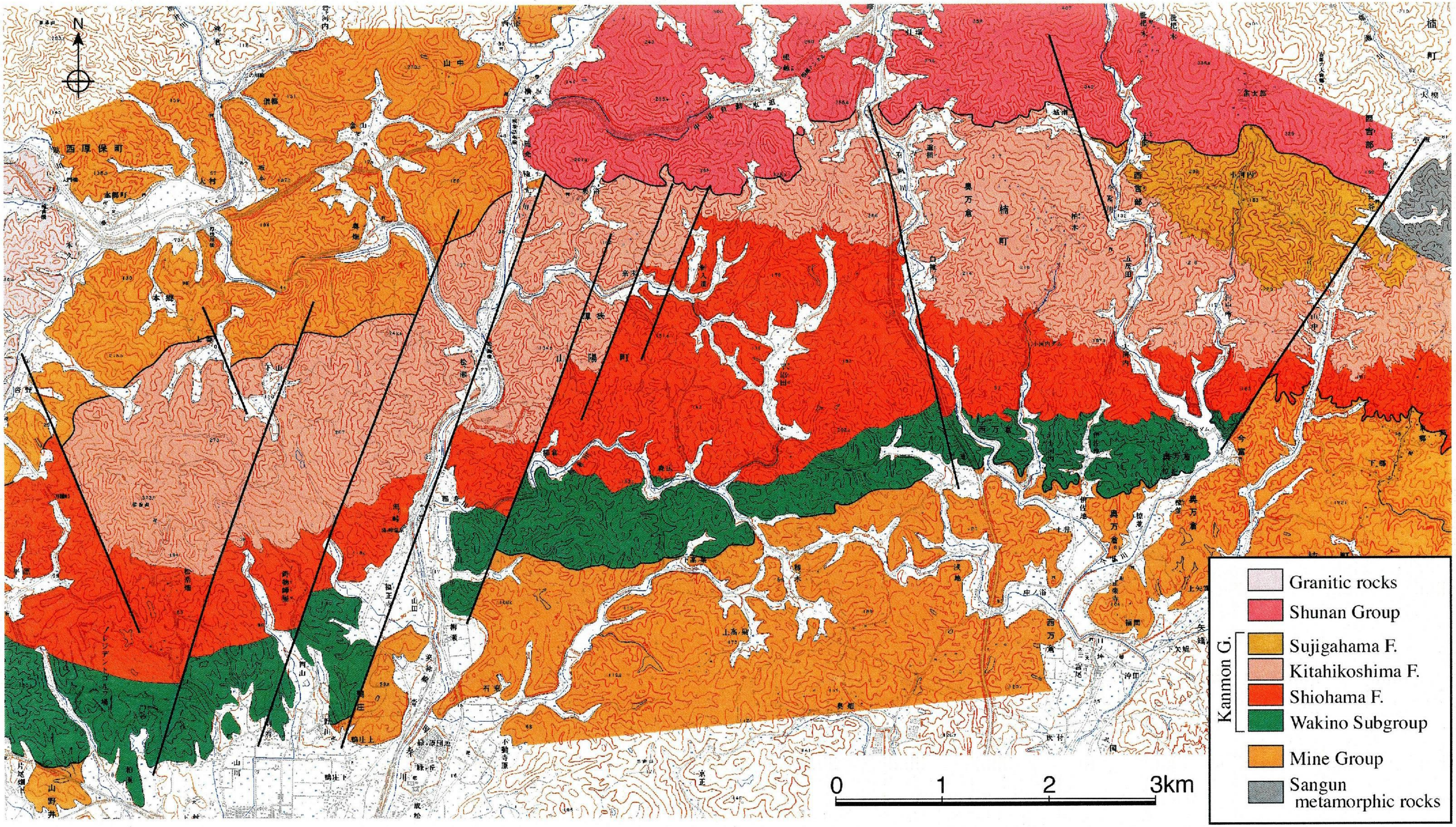


Fig. 9. Geological Map of Asa area. "Asa", "Ajisu", "Isa" and "Yunokuchi" published by Geographical Survey Institute of Japan)

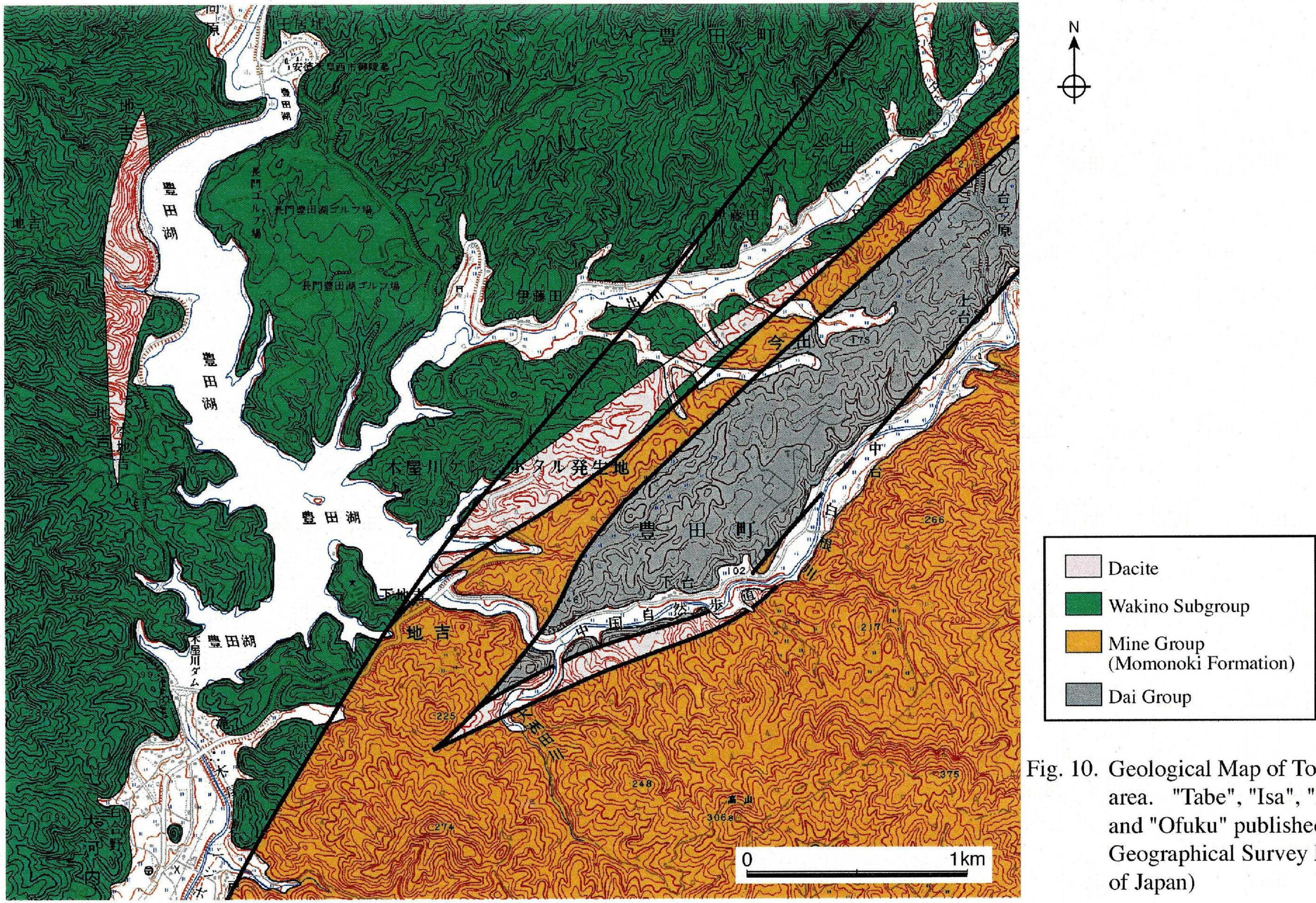


Fig. 10. Geological Map of Toyota area. "Tabe", "Isa", "Nishiiti" and "Ofuku" published by Geographical Survey Institute of Japan)

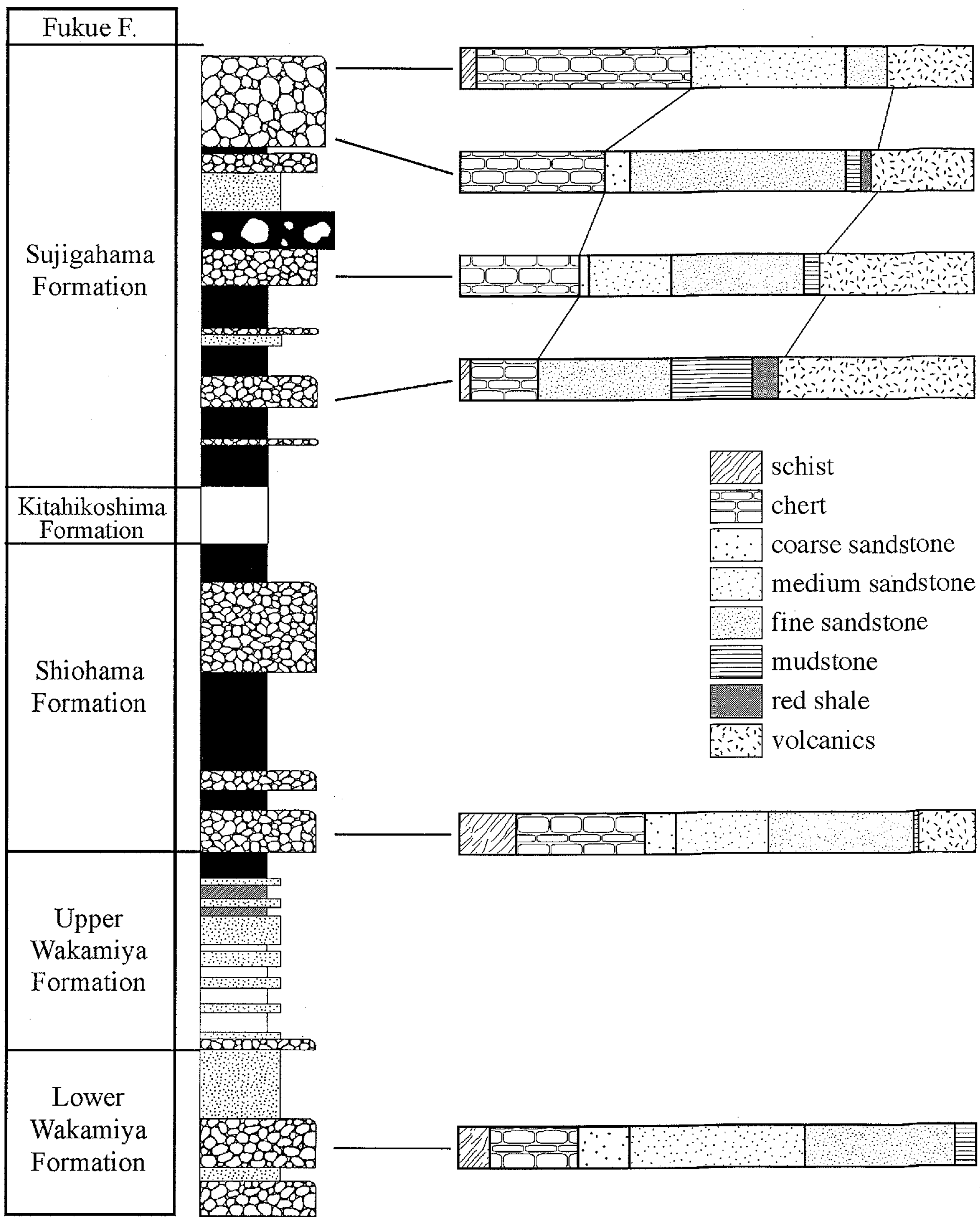


Fig. 11. Compositional variation of conglomerate in the Kanmon Group.

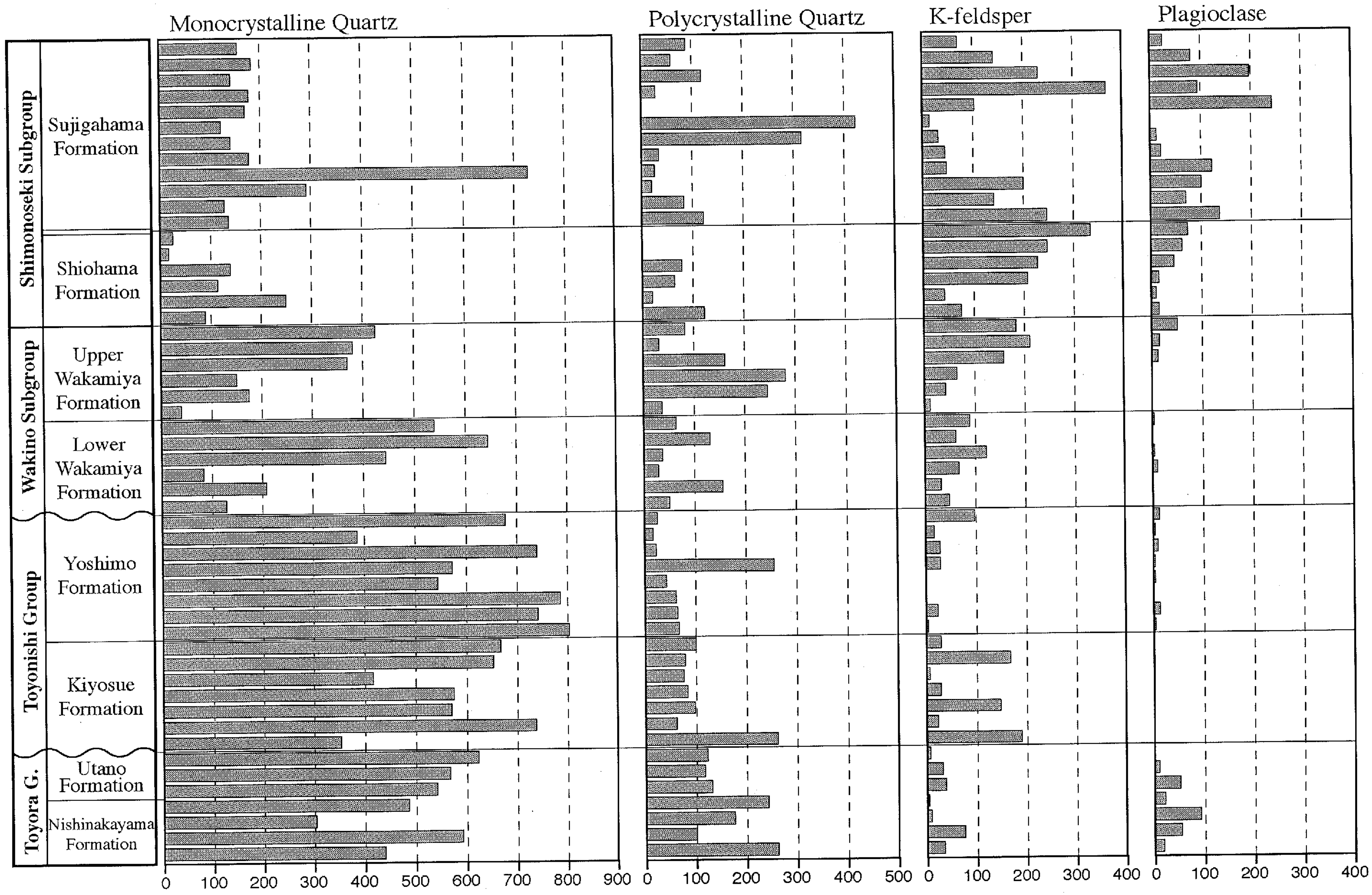


Fig. 12. Conpositional variation of sandstone (Mineral grains).

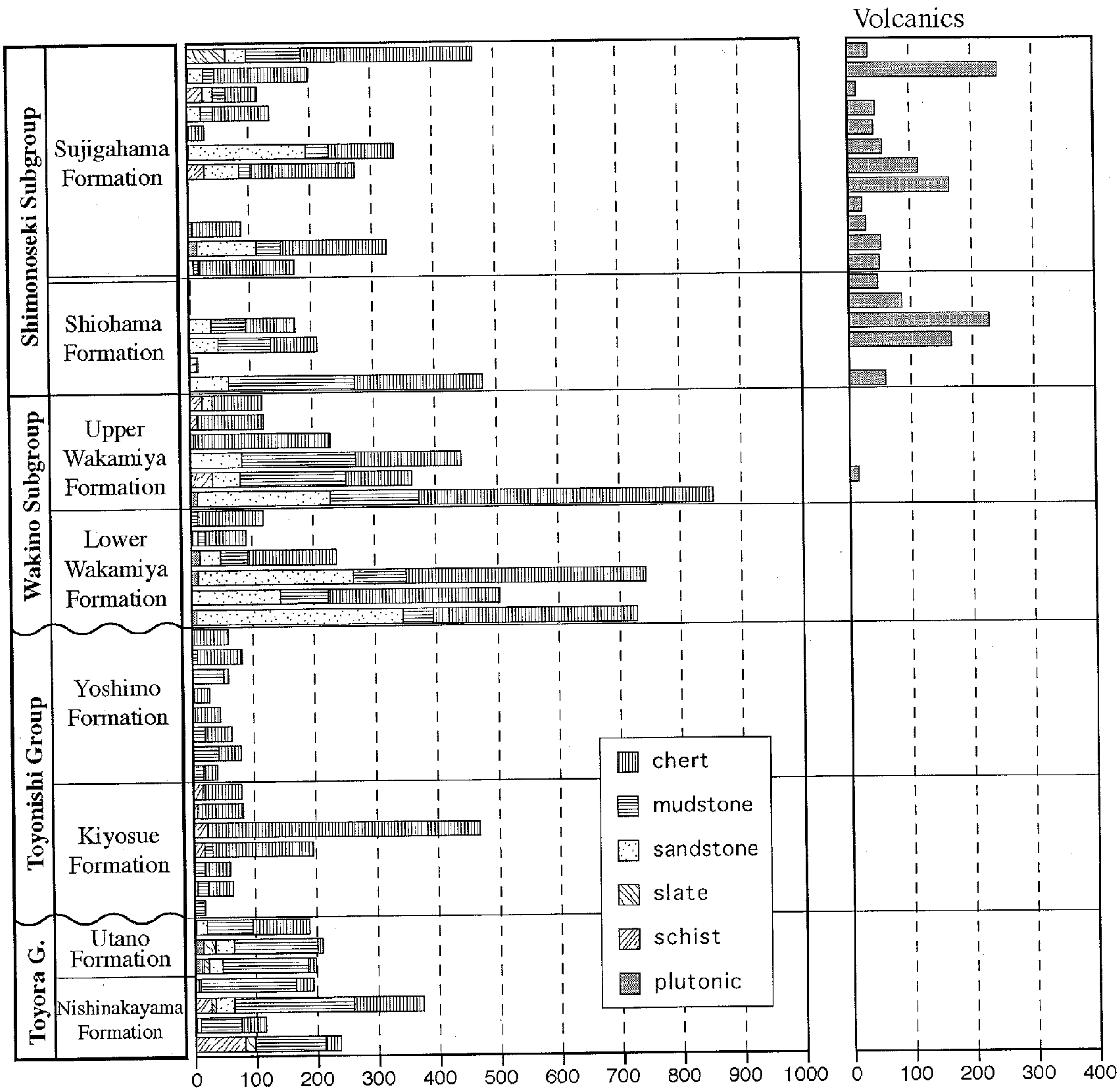
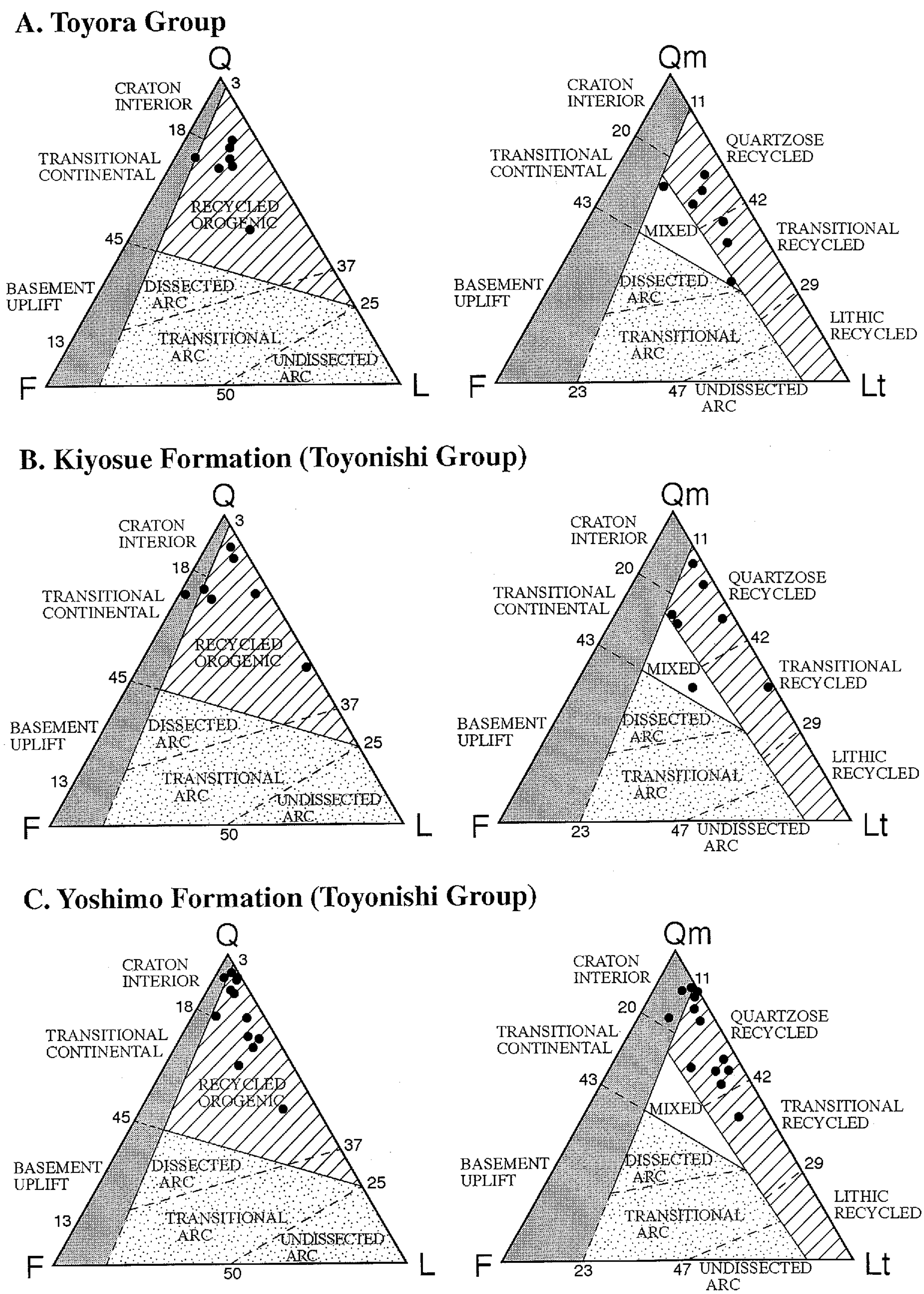


Fig. 13. Conpositional variation of sandstone (Rock fragments).



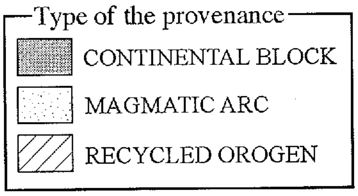


Fig. 14. Triangular plots of the framework mode of the Toyora and Toyonishi Groups.

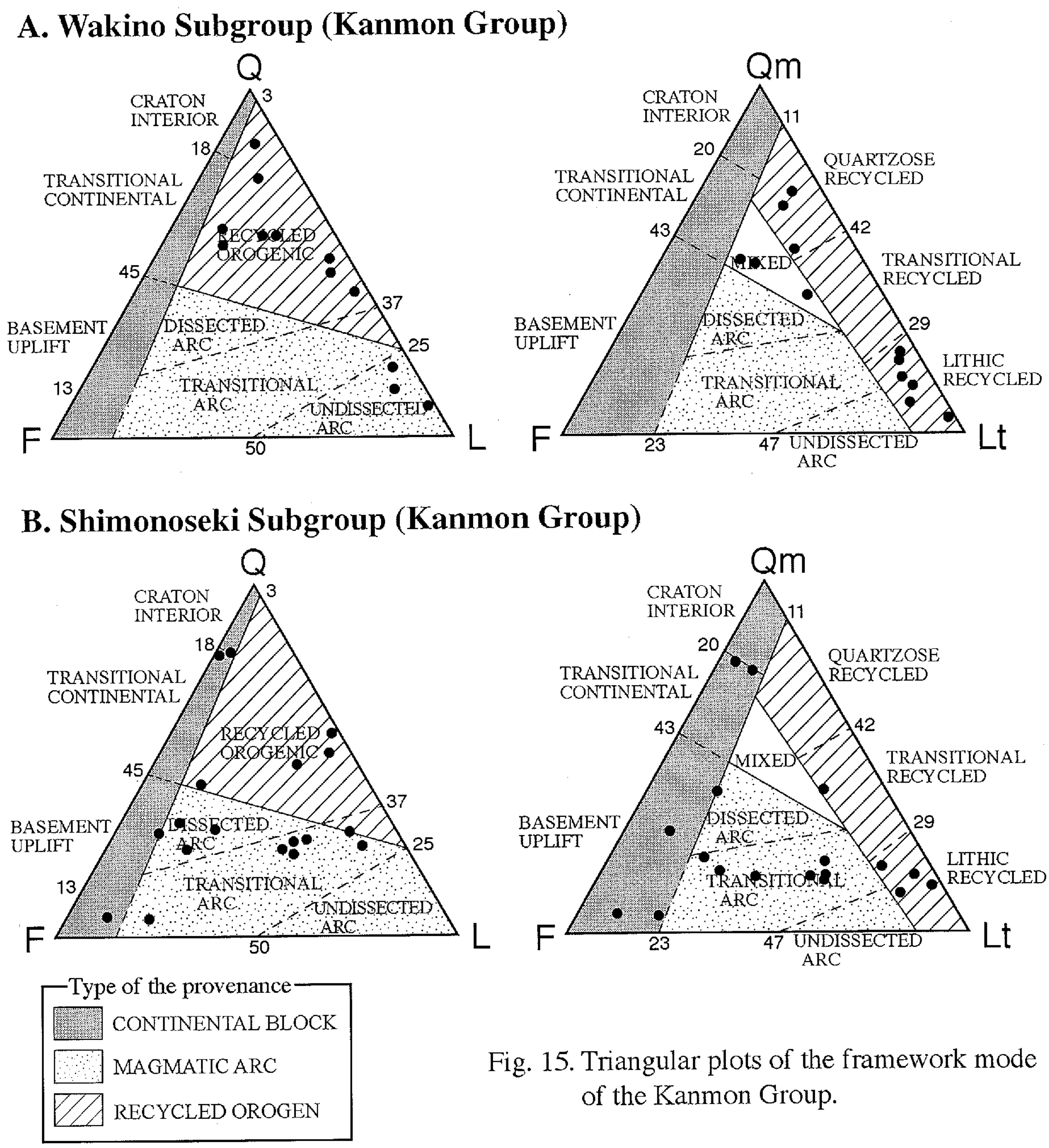


Fig. 15. Triangular plots of the framework mode of the Kanmon Group.

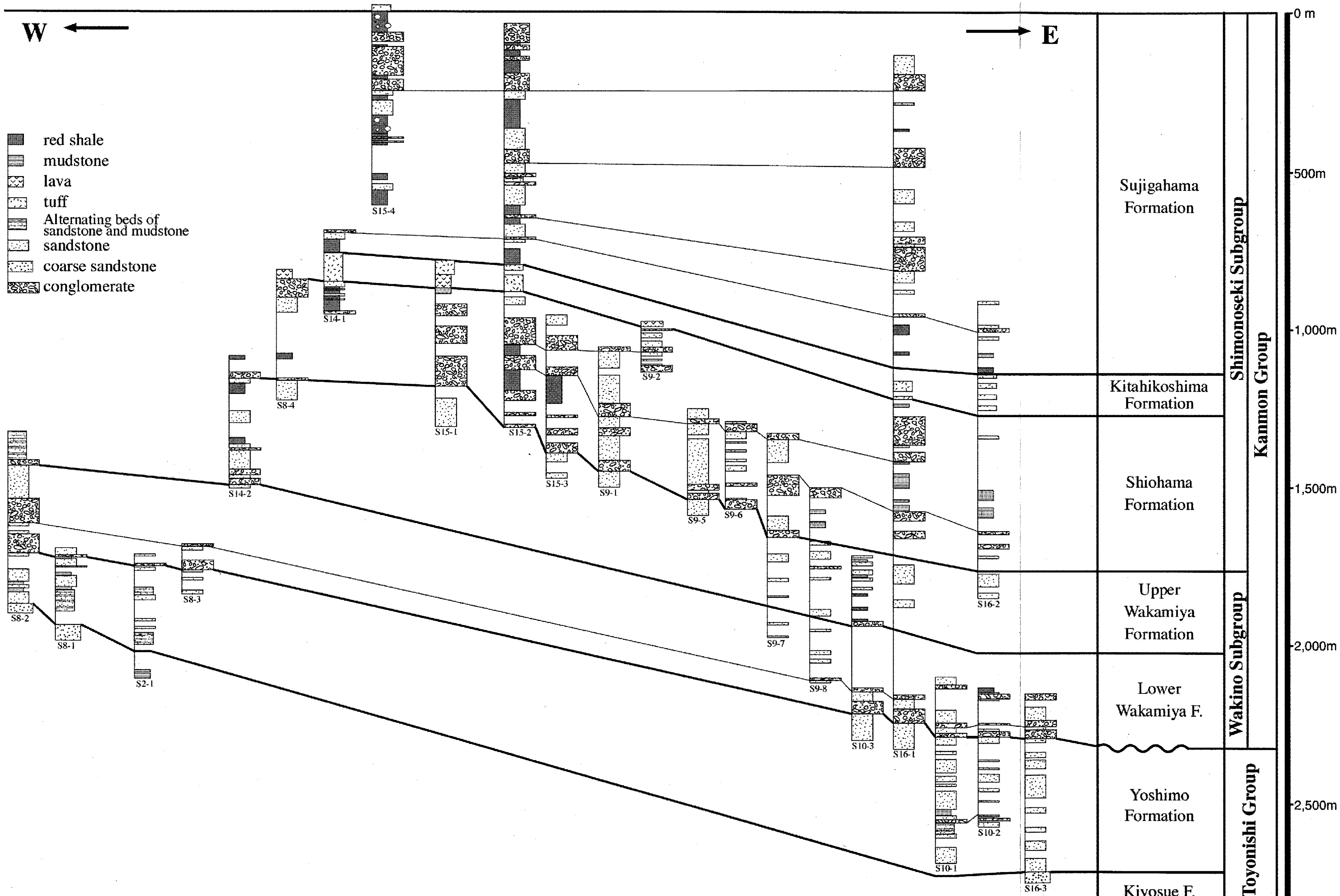


Fig. 16. Columnar sections of the Toyonishi and Kanmon Groups in the Yoshimo - Kikugawa area.

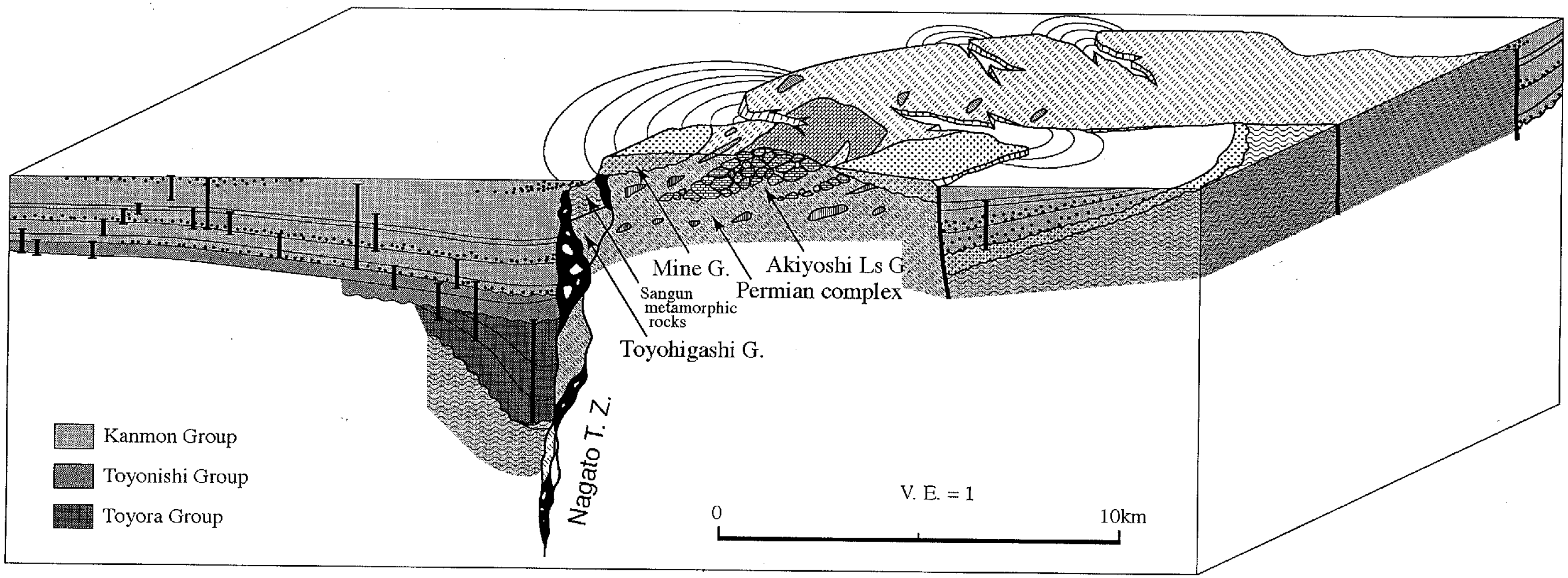


Fig. 17. Schematic reconstruction of the sedimentary basin.

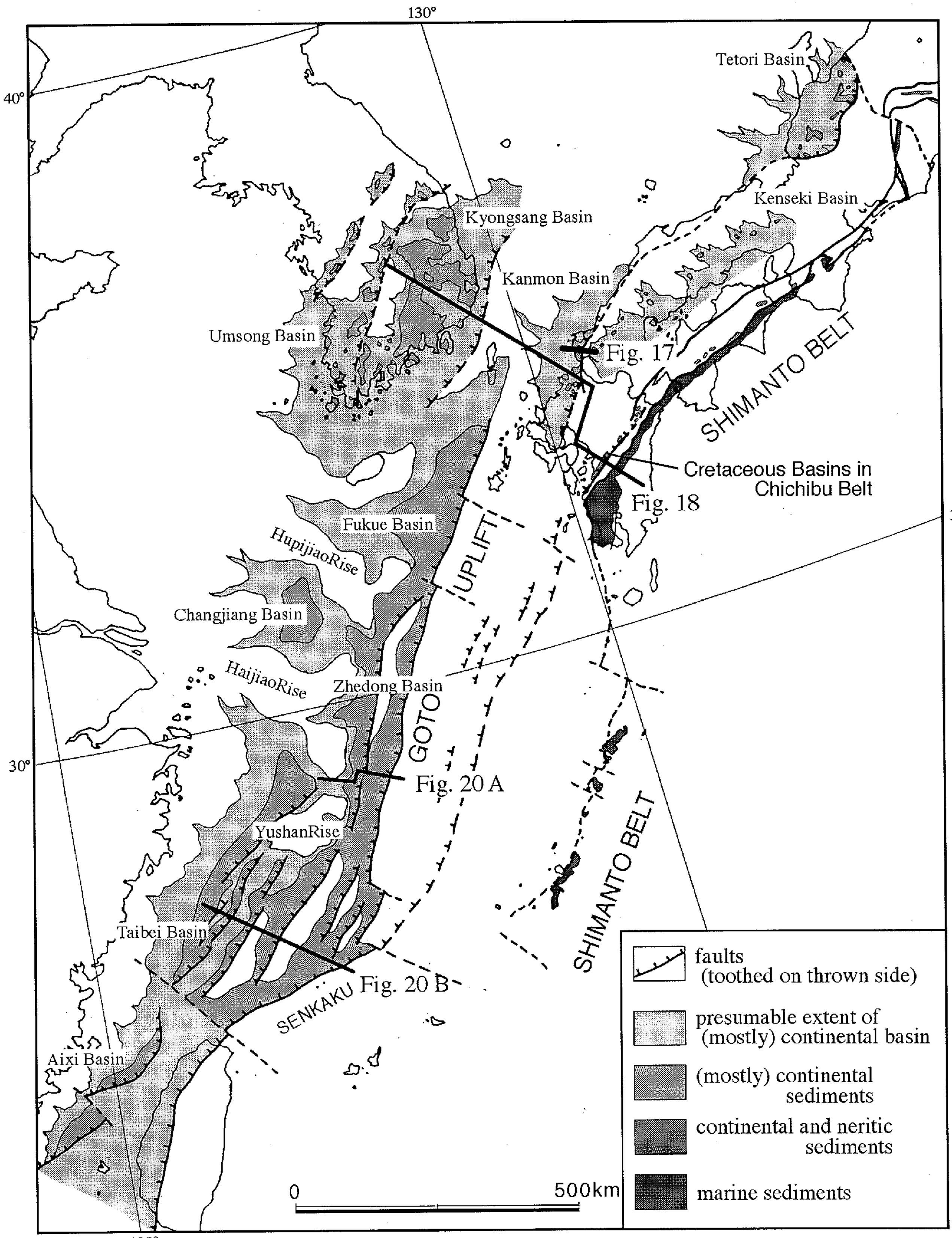


Fig. 18. Distribution of the Lower Cretaceous sedimentary basins from East China Sea to Southwest Japan.

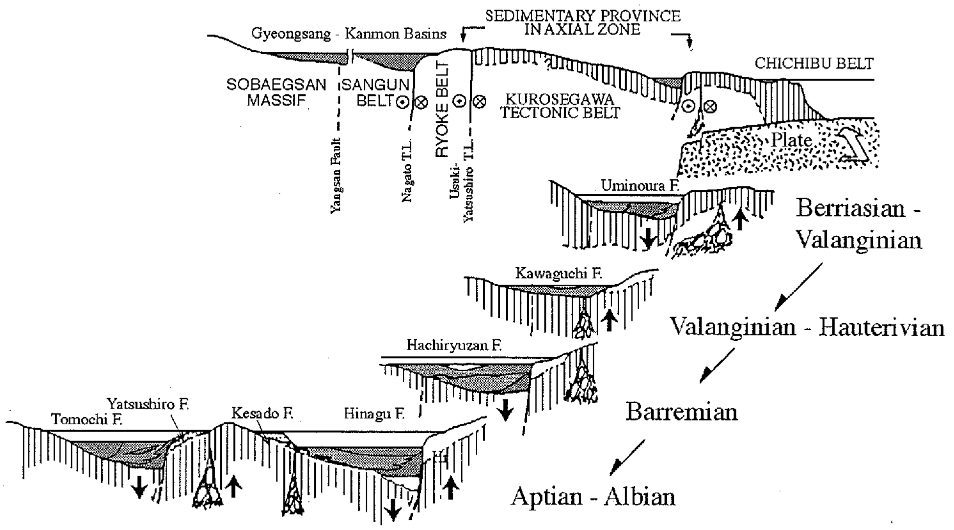


Fig. 19. Basin profiles from South Korea to Kyushu (Sakai et al., 1992).

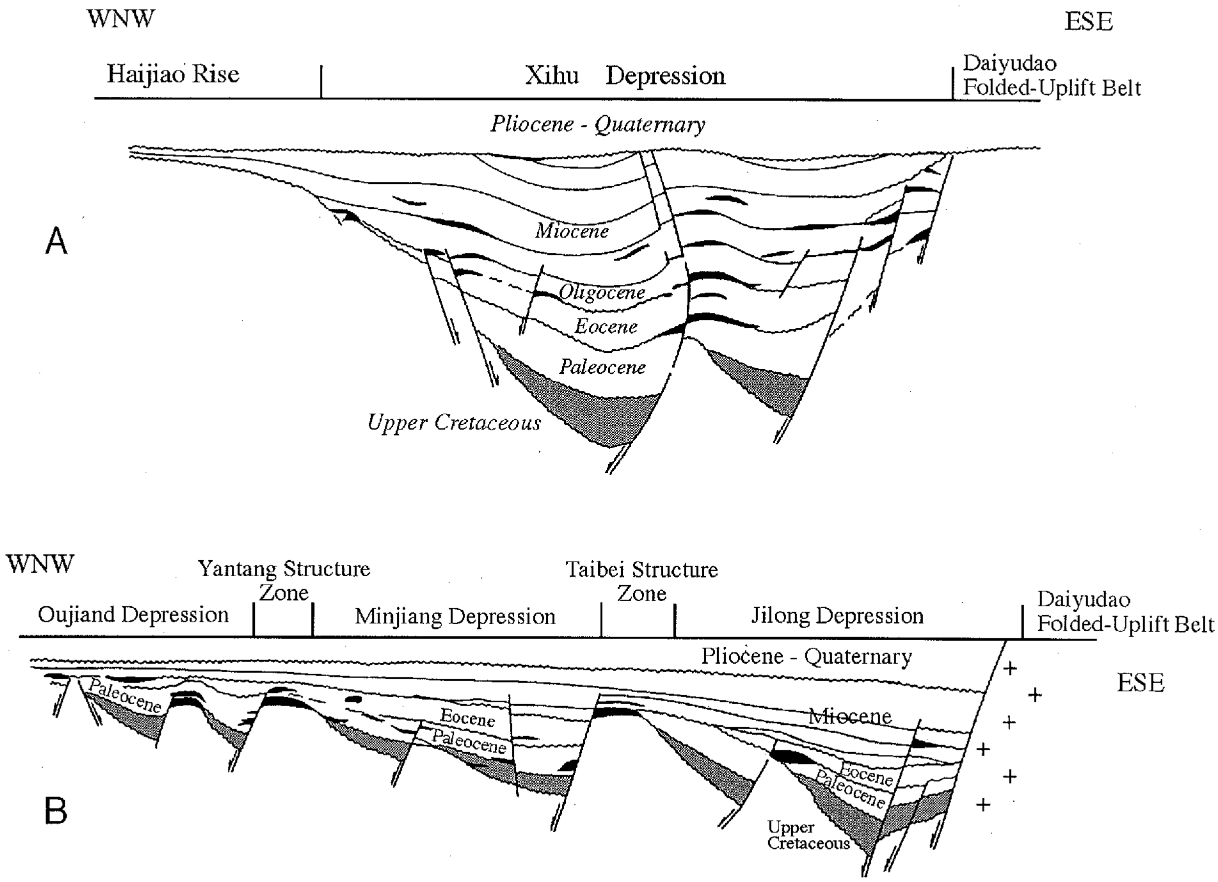


Fig. 20. Sketch of seismic profiles in the East China Sea (Zhou et al., 1989).
A : the Zhedong Basin, B : the Taibei Basin

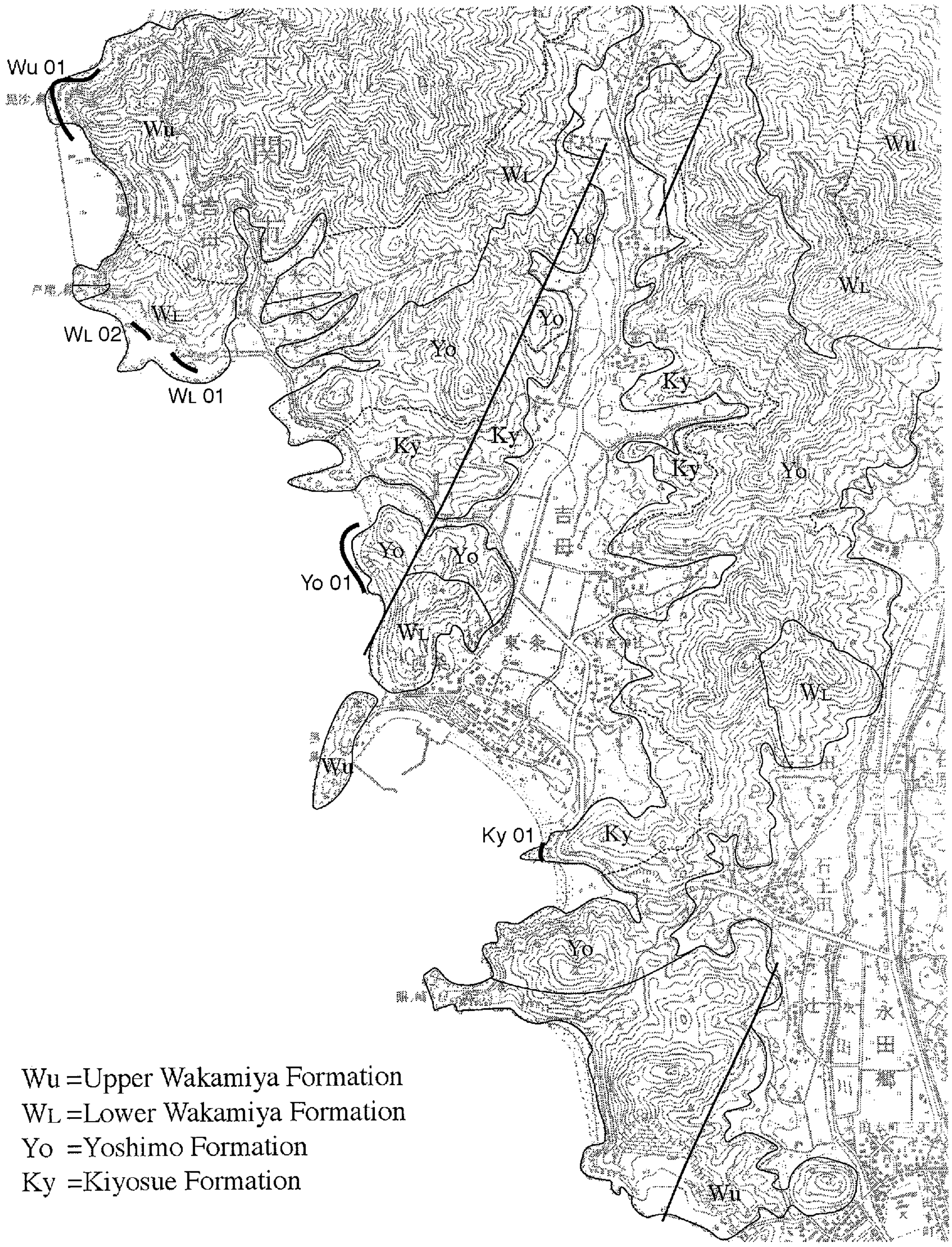


Fig. 21. Locality map of columnar sections of the Toyonishi Group and Wakino Subgroup. (a part of 1:25,000 map of "Futaoijima", "Kawatanaonsen" and "Yasuoka" published by Geographical Survey Institute of Japan)

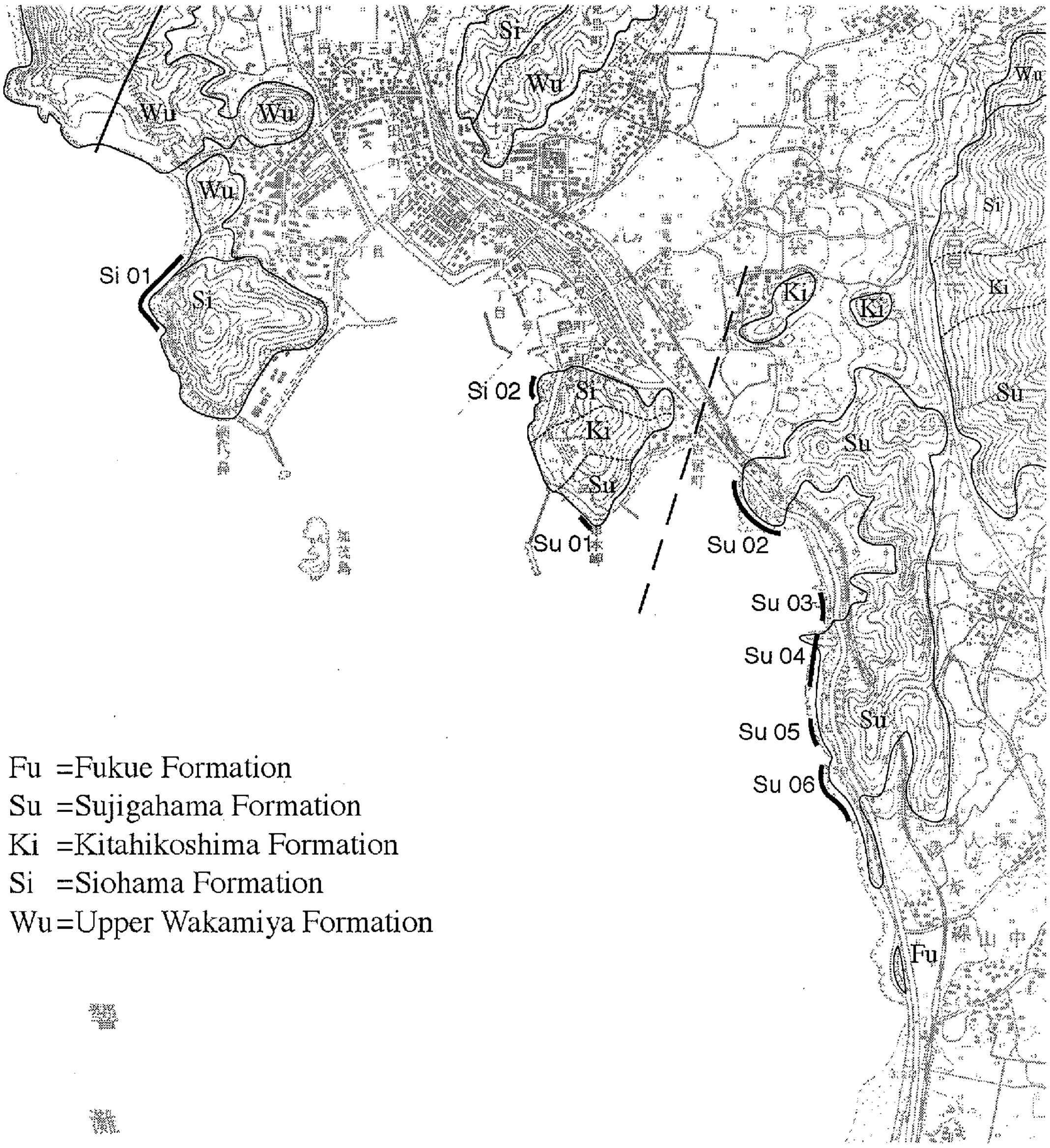


Fig. 22. Locality map of columnar sections of the Shimonoseki Subgroup. (a part of 1:25,000 map of "Yasuoka" published by Geographical Survey Institute of Japan)

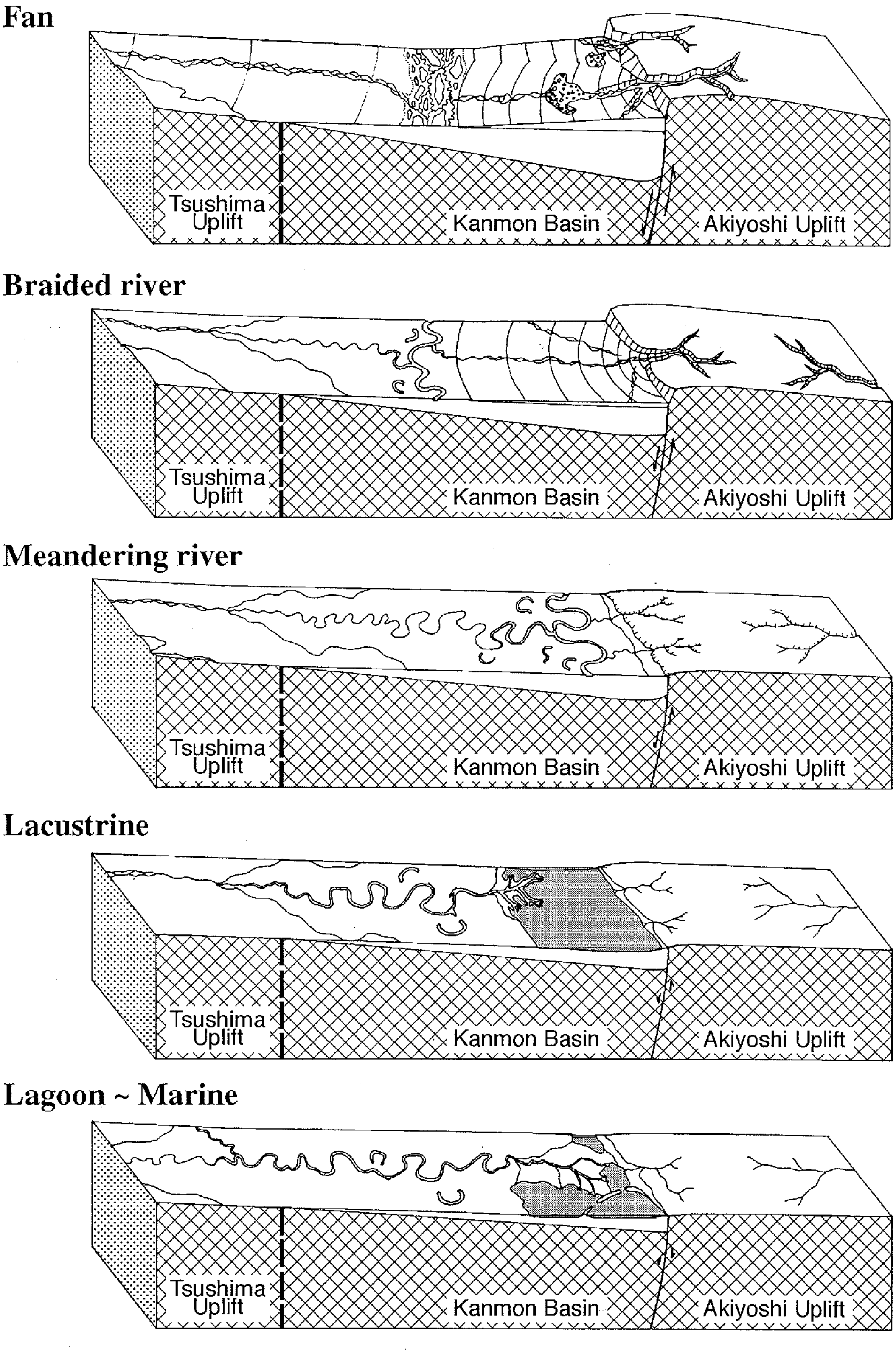


Fig.23. Schematic depositional environments.

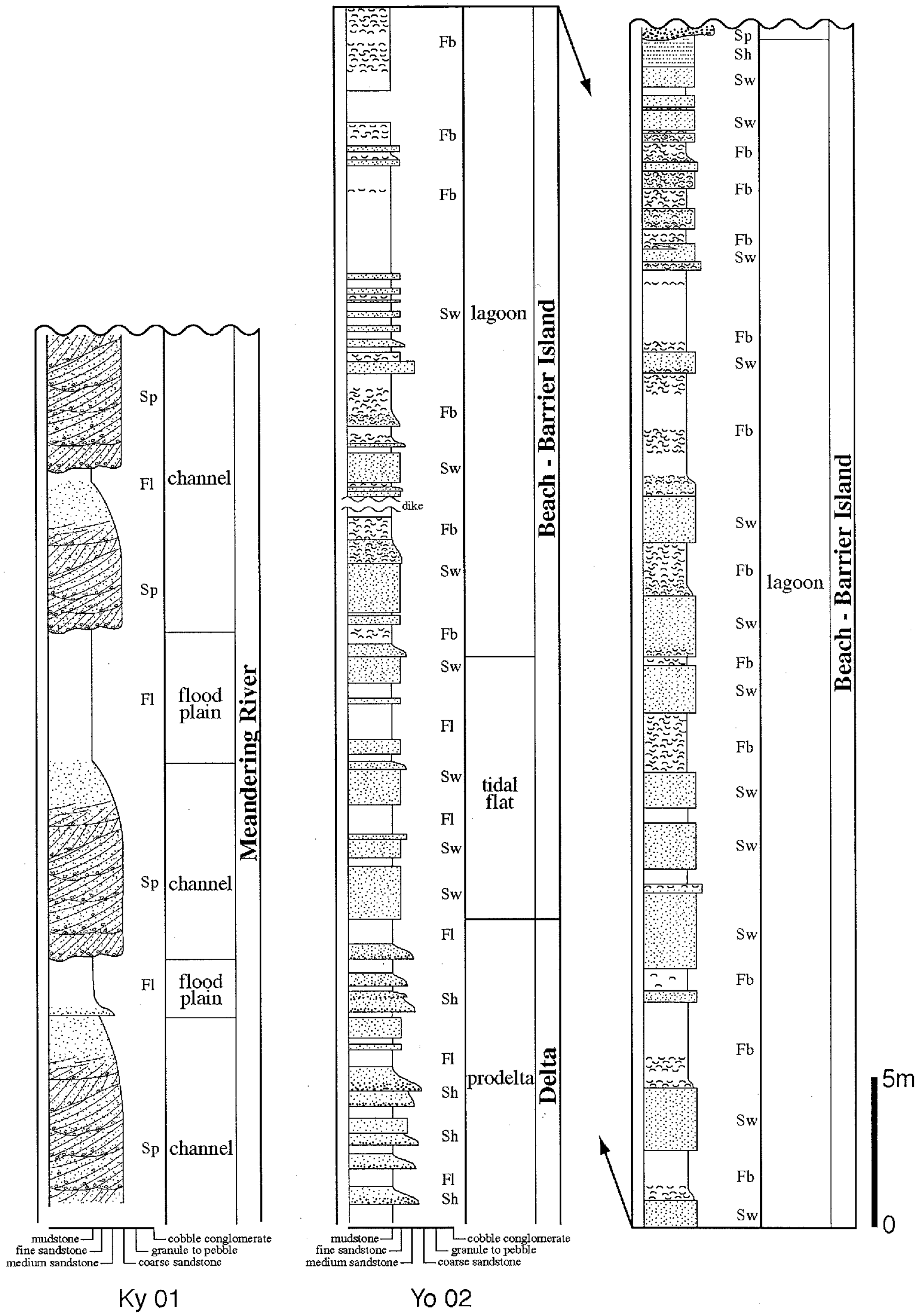


Fig. 24. Columnar section showing sedimentary facies of the Toyonishi Group.

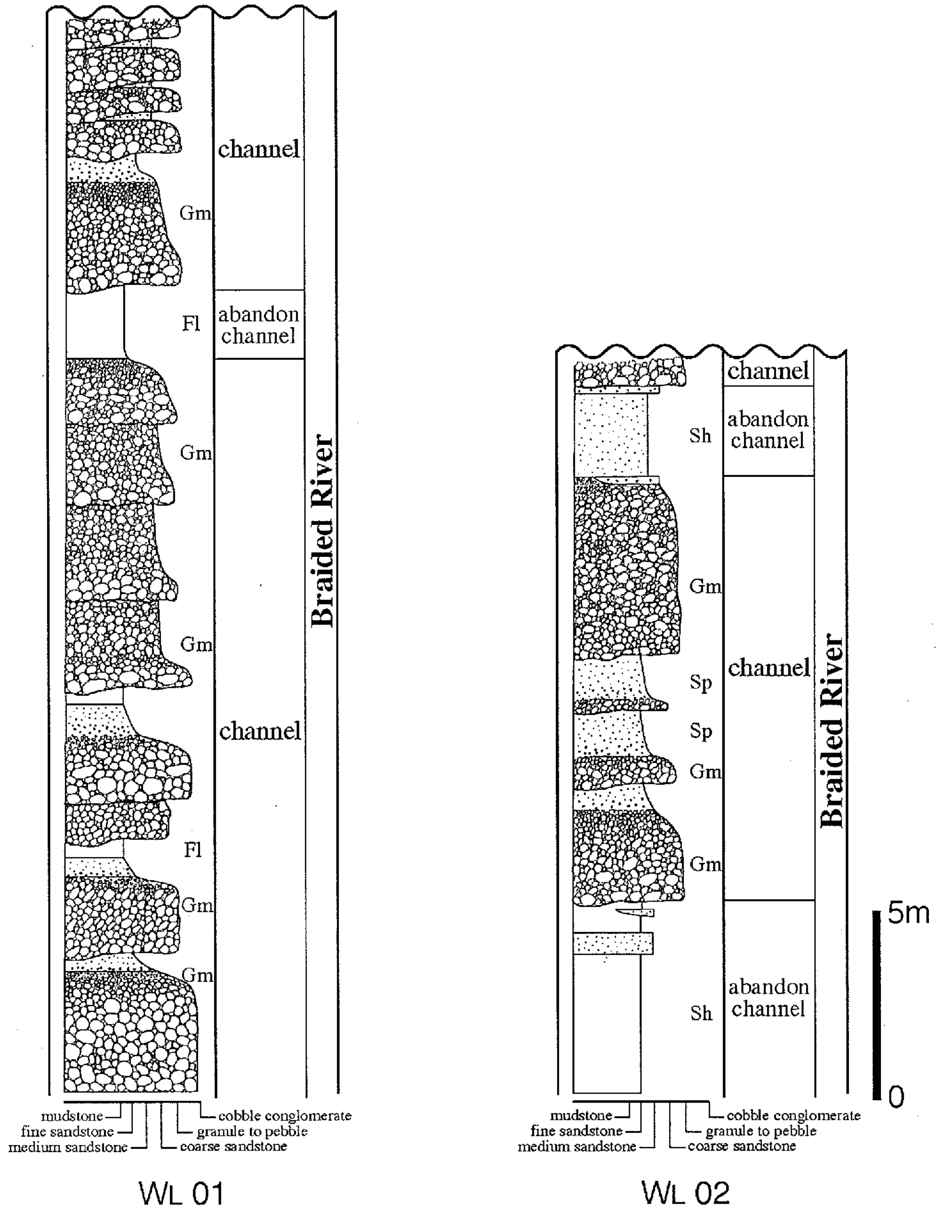


Fig. 25. Columnar section showing sedimentary facies of the Lower Wakamiya formation.

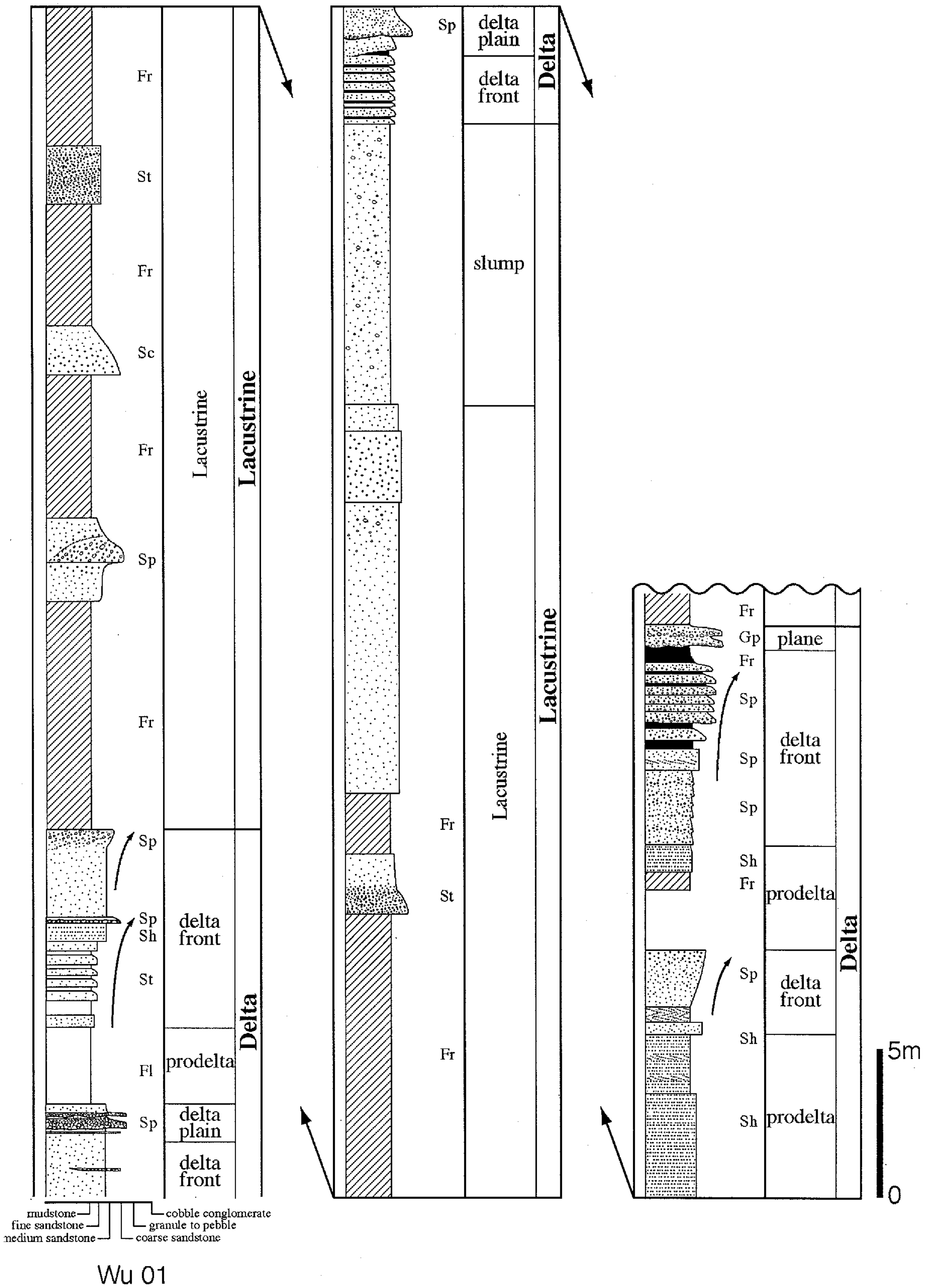


Fig. 26. Columnar section showing sedimentary facies of the Upper Wakamiya formation.

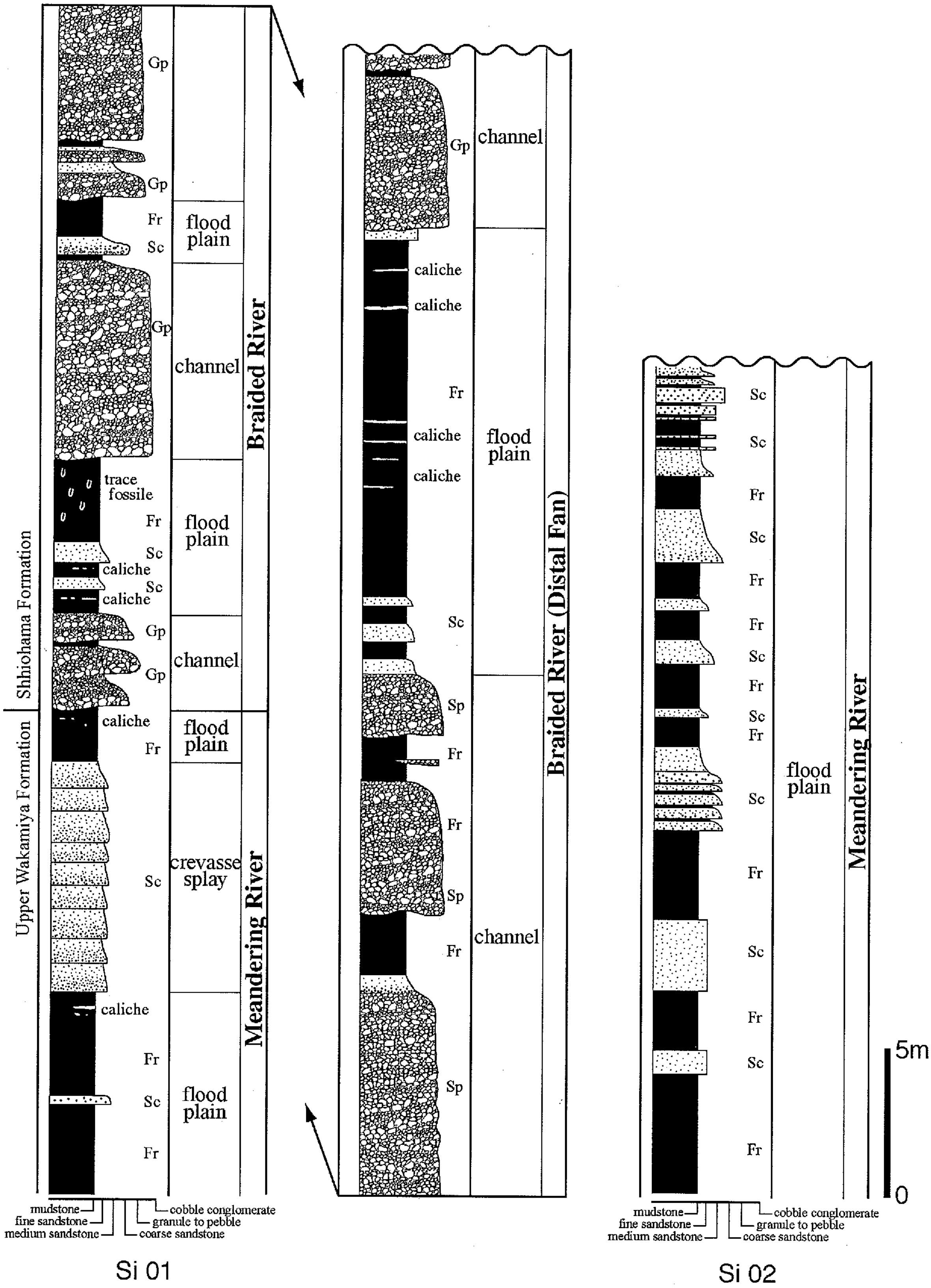


Fig. 27. Columnar section showing sedimentary facies of the Siohama formation.

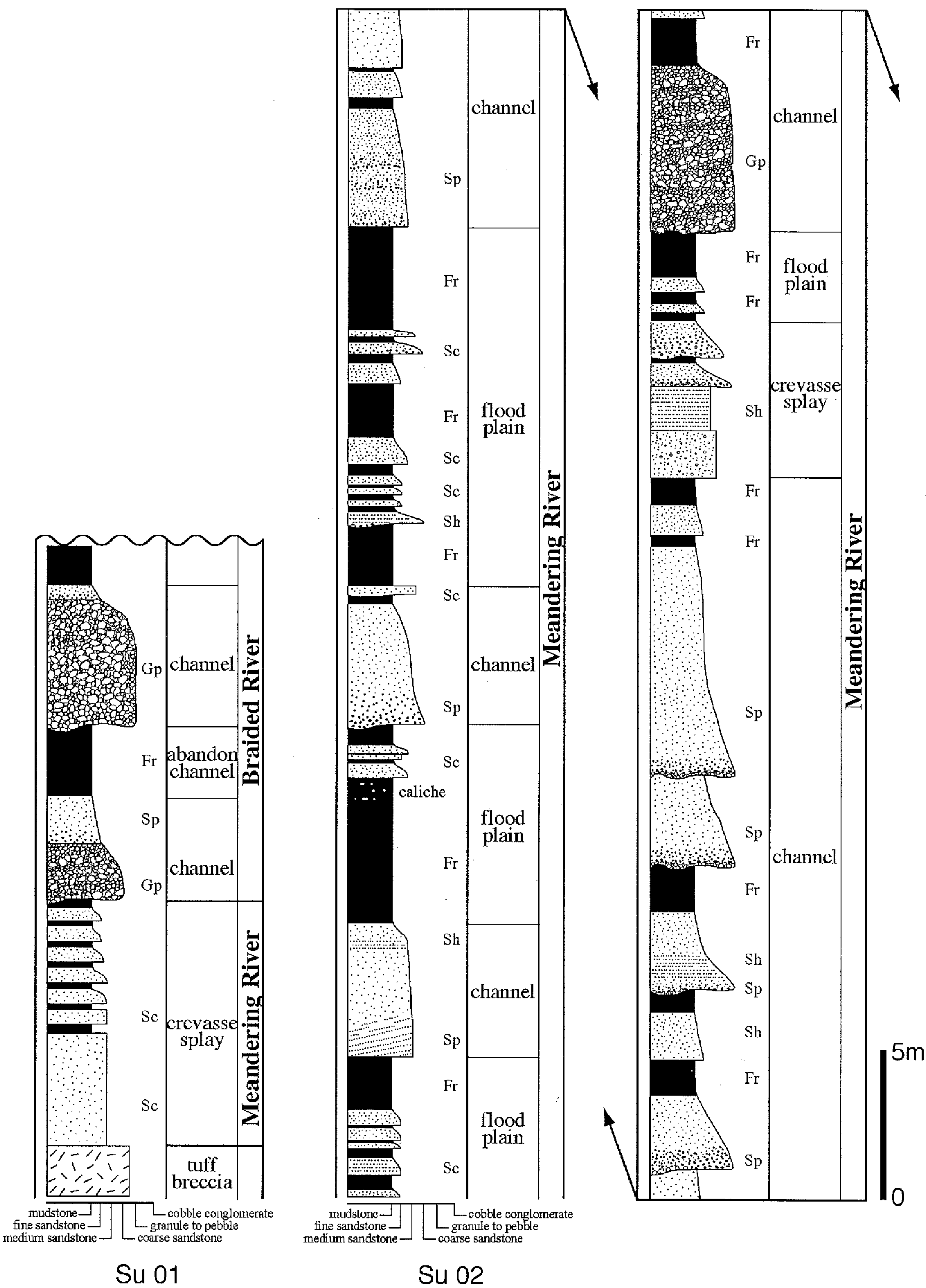


Fig. 28. Columnar section showing sedimentary facies of the Sujigahama formation.

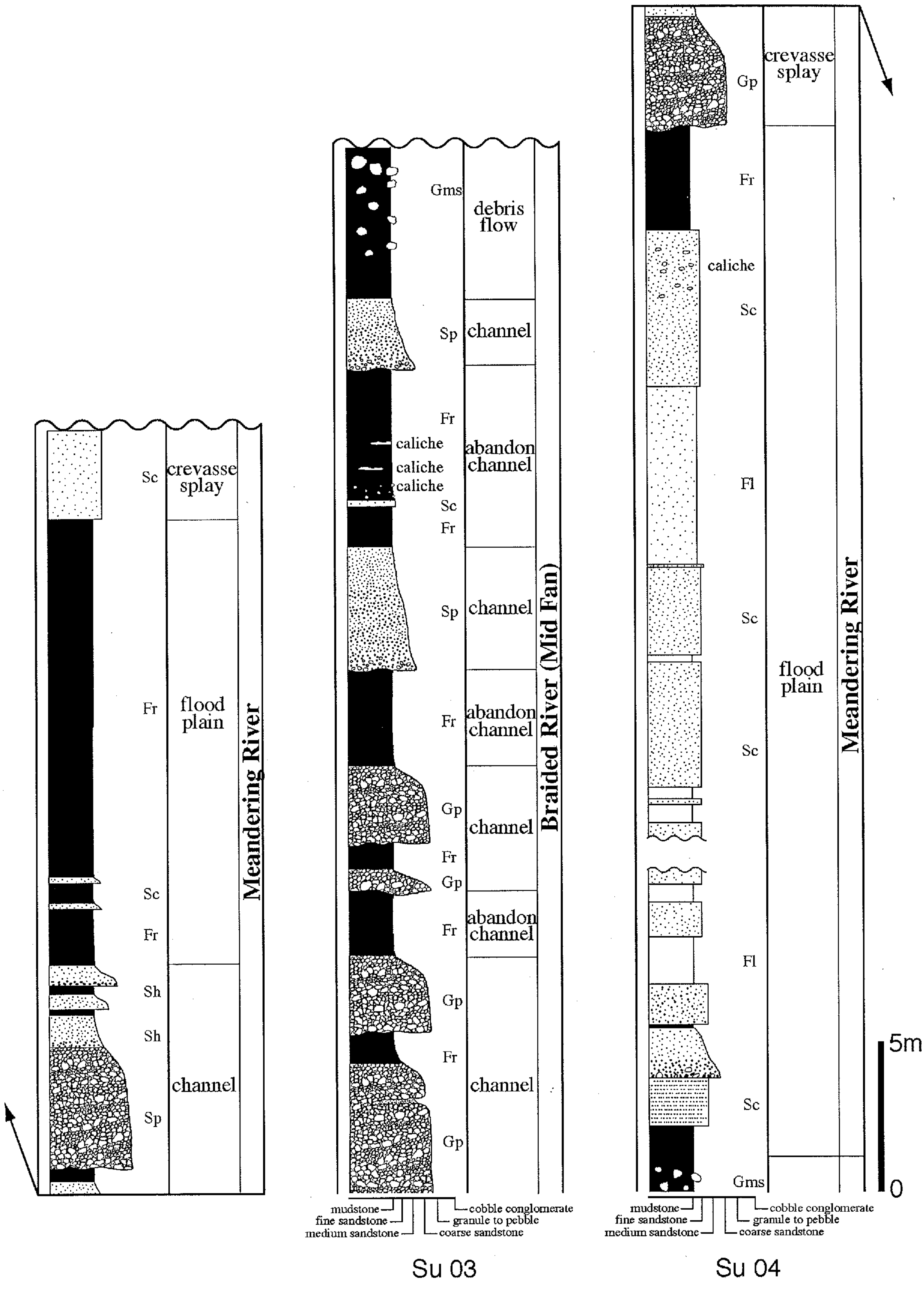


Fig. 29. Columnar section showing sedimentary facies of the Sujigahama formation.

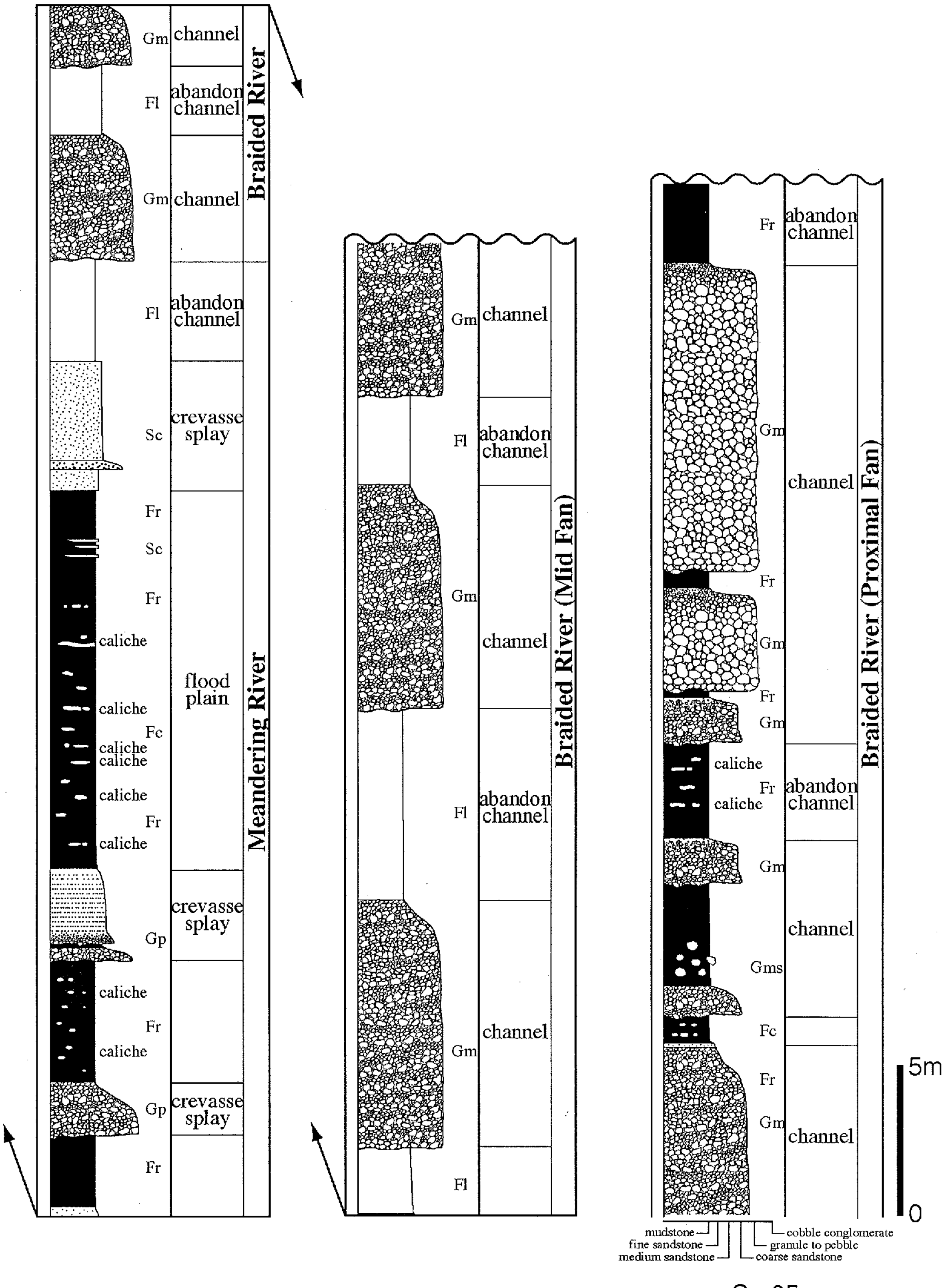


Fig. 30. Columnar section showing sedimentary facies of the Sujigahama formation.

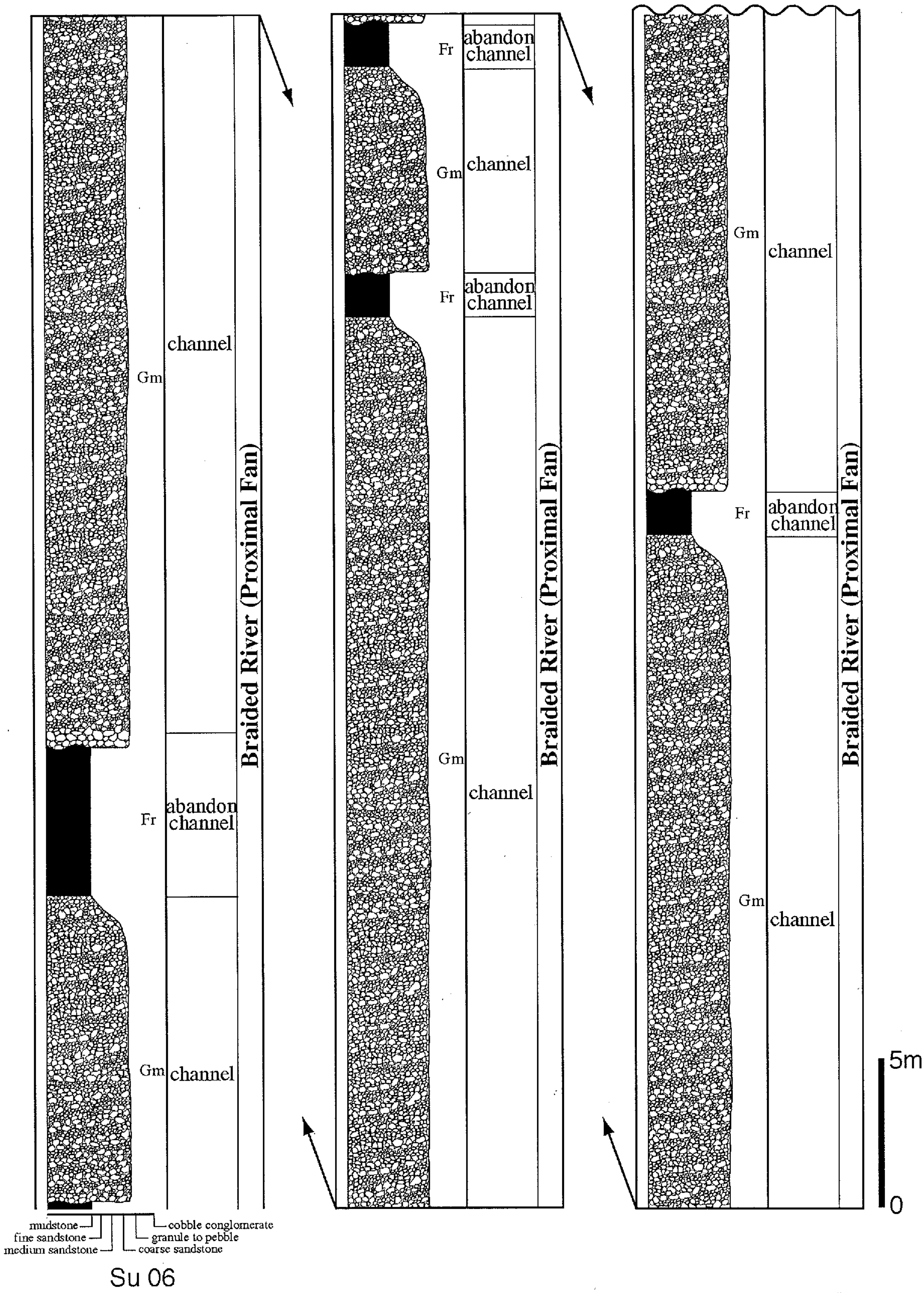


Fig. 31. Columnar section showing sedimentary facies of the Sujigahama formation.

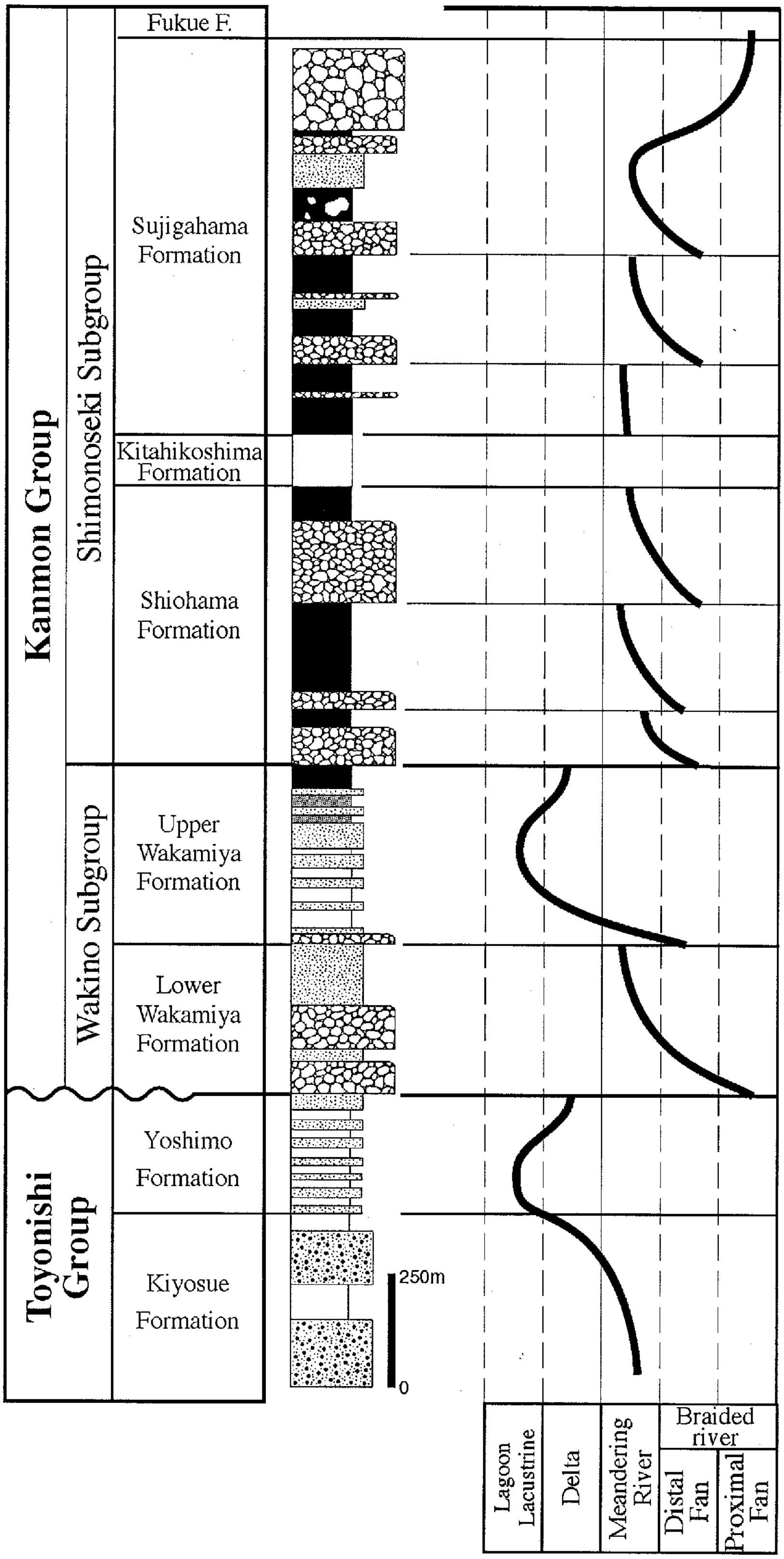


Fig. 32. Diagrammatic facies changes of the Toyonishi and Kanmon Groups.

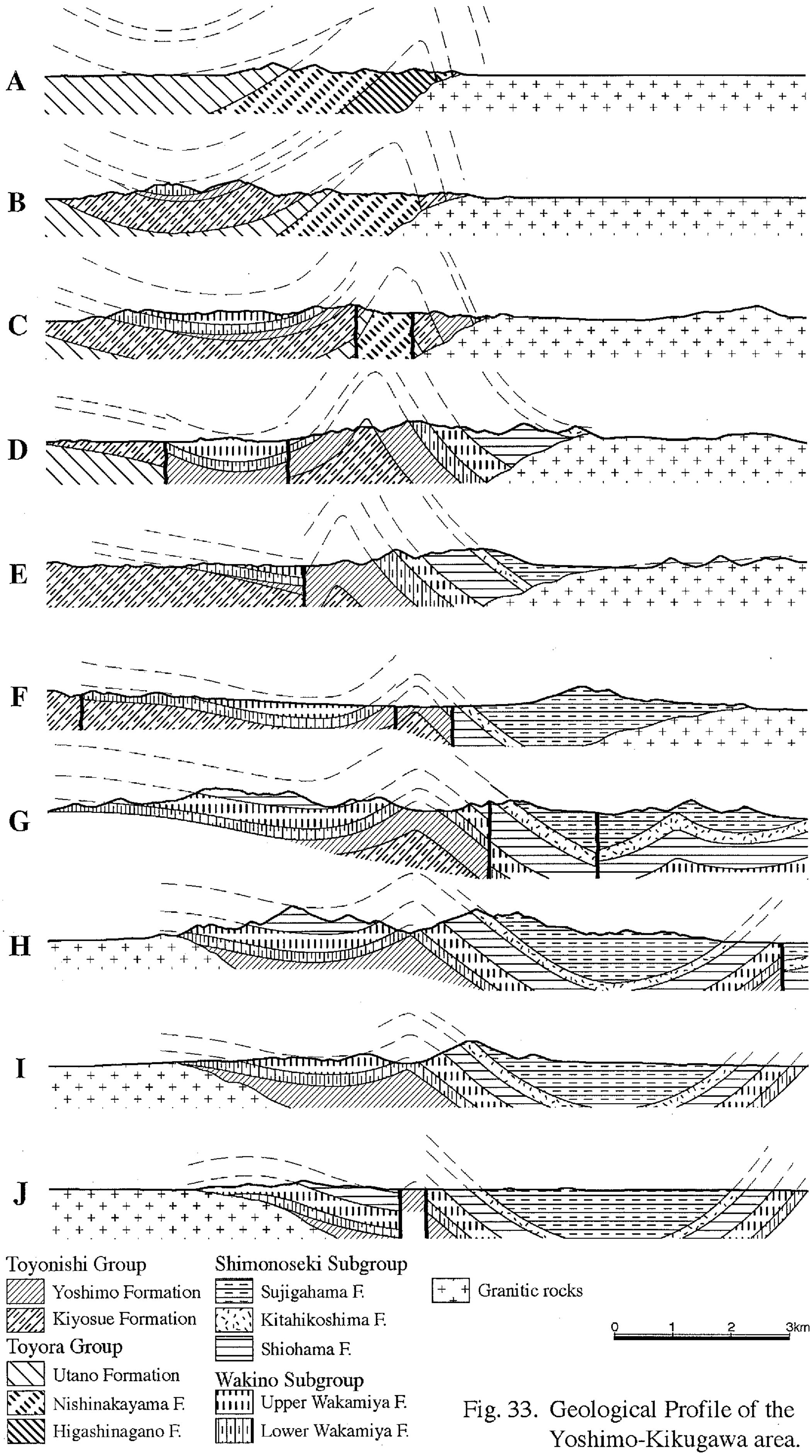


Fig. 33. Geological Profile of the Yoshimo-Kikugawa area.

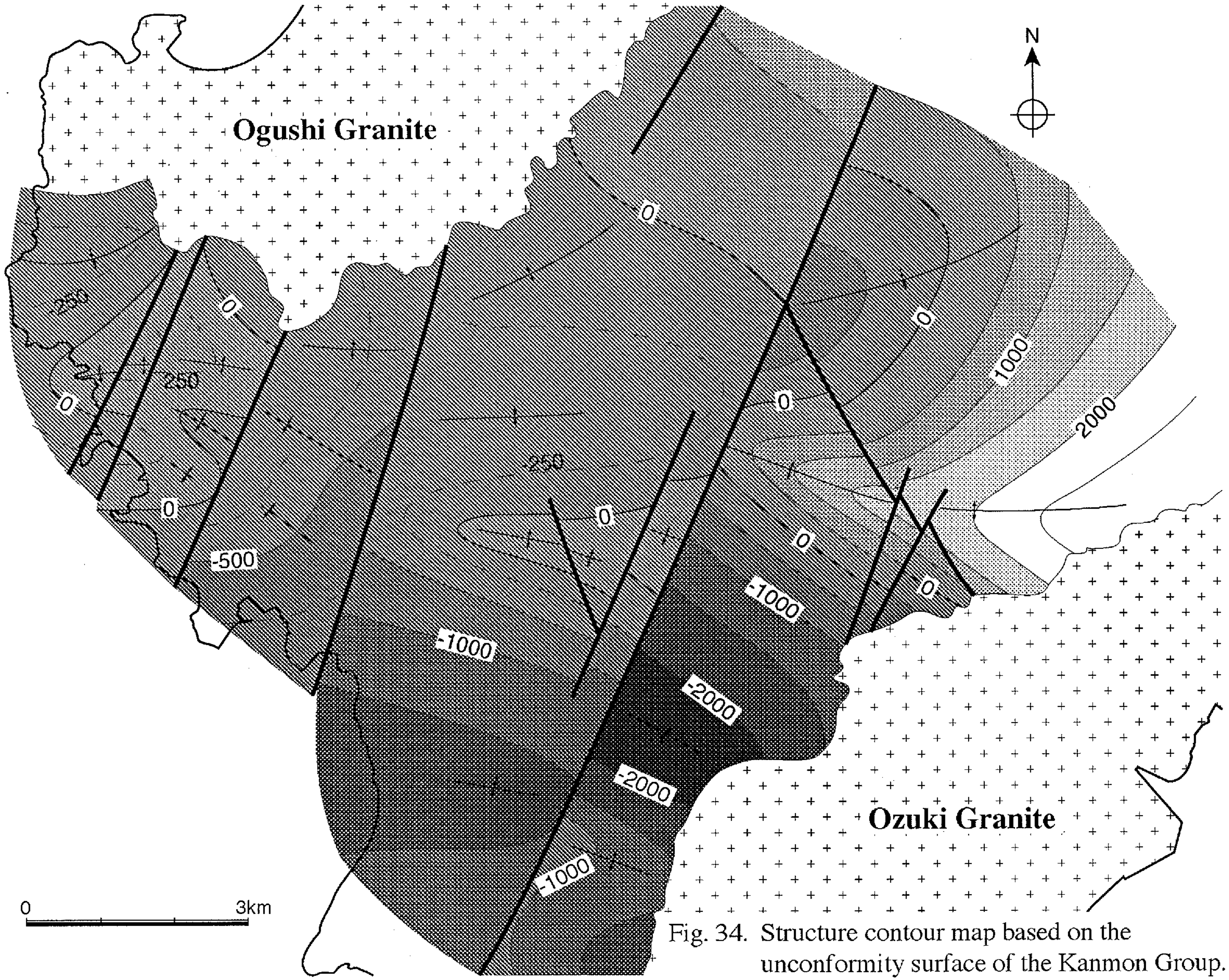


Fig. 34. Structure contour map based on the unconformity surface of the Kanmon Group.

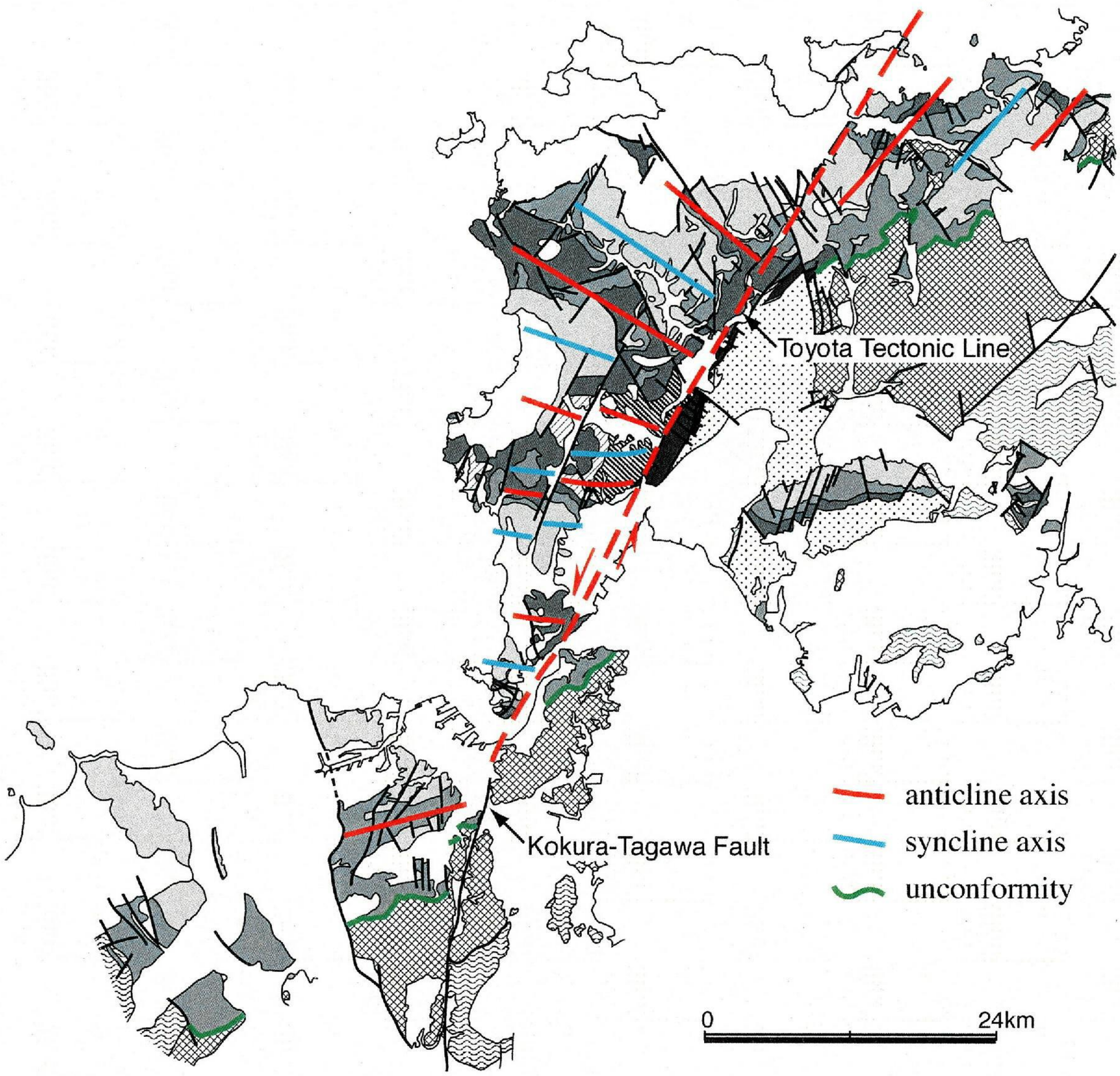


Fig. 35. Geologic structures in the Upper Mesozoic. Left-lateral movement of the Kikugawa Fault (Quarternary) are relocated.

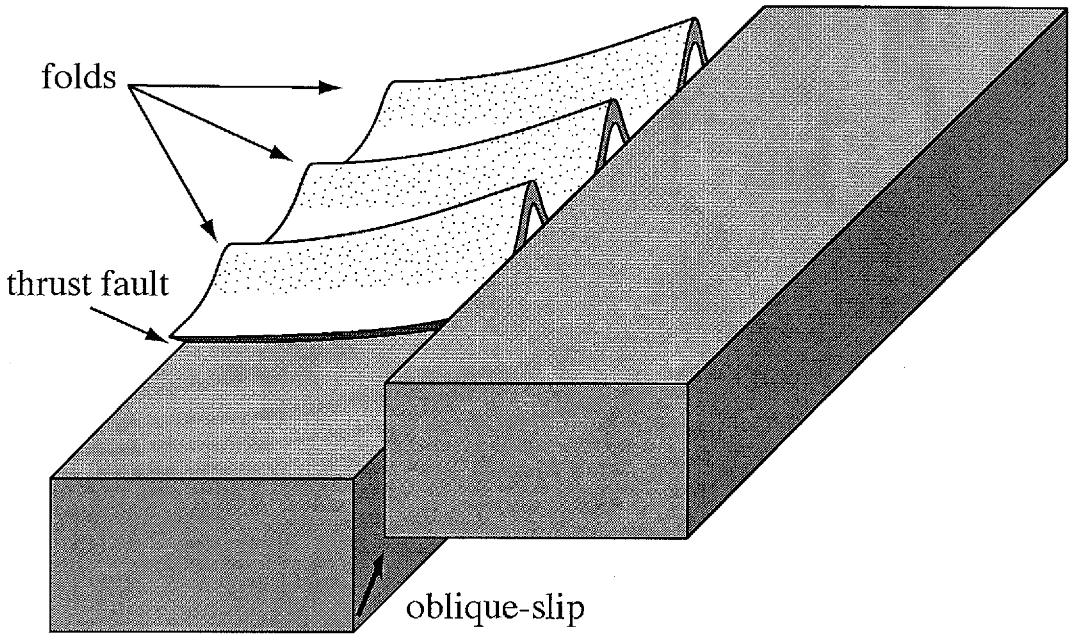


Fig. 36. Deformation model of the Upper Mesozoic formations caused by the Toyota Tectonic Line.

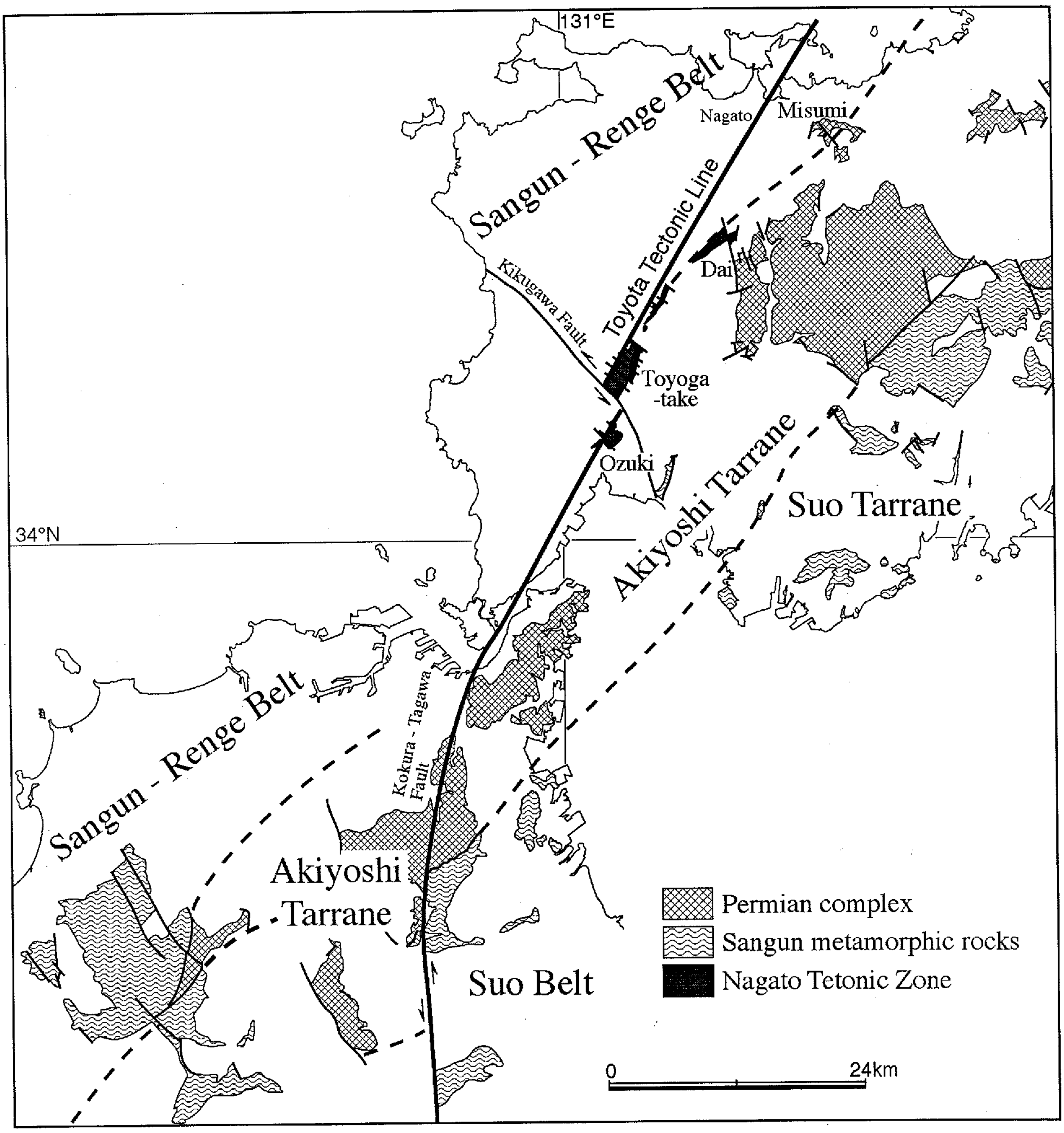


Fig. 37. Tectonic framewrok in North Kyushu to western Yamaguchi Prefecture.

Late Jurassic - Earliest Cretaceous

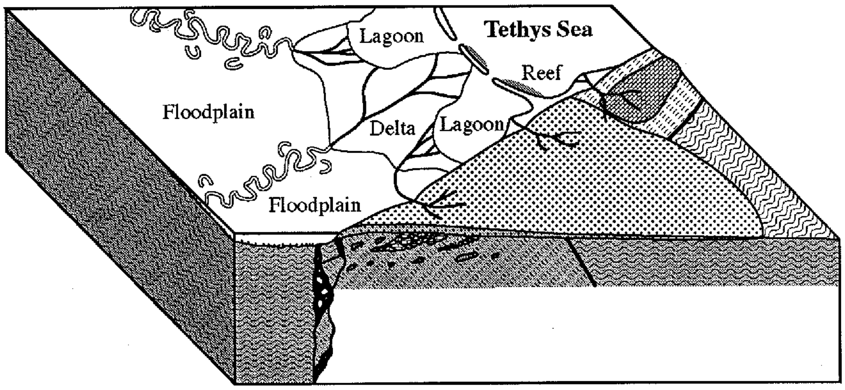


Fig. 38. Schematic paleogeographical profiles from North Kyushu to Southwestern Yamaguchi Prefecture.

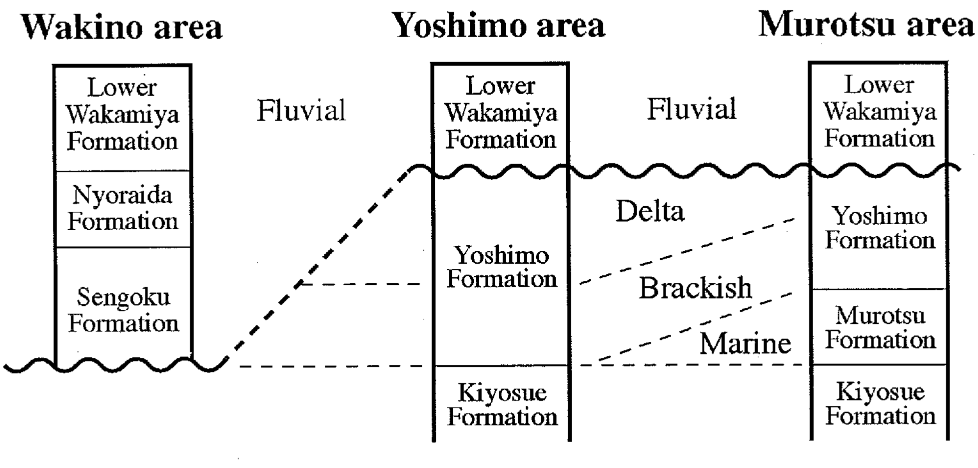
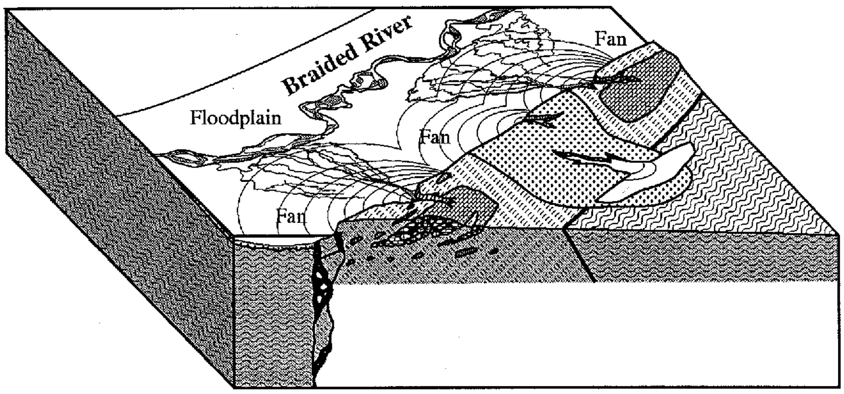


Fig. 39. Correlation of the sedimentary environment from North Kyushu to Southwestern Yamaguchi Prefecture.

A. Hauterivian



B. Barremian

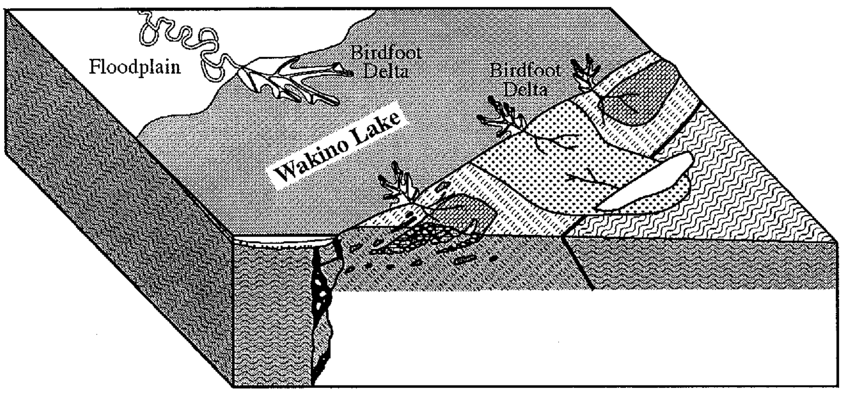
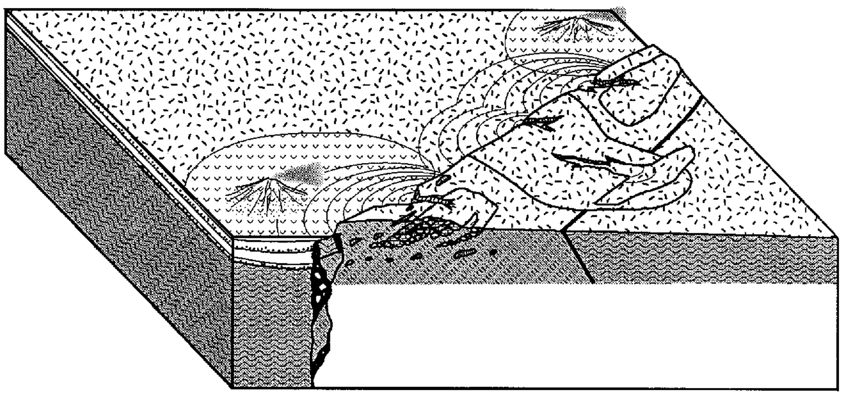


Fig. 40. Schematic paleogeographical profiles from North Kyushu to Southwestern Yamaguchi Prefecture.

A. Aptian



B. Albian

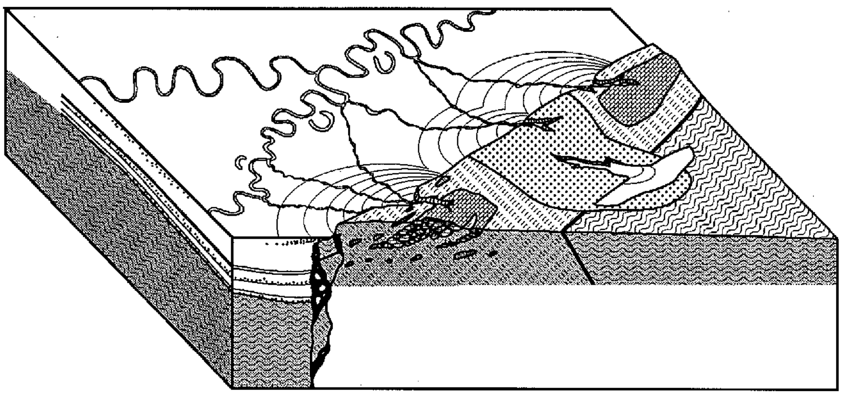


Fig. 41. Schematic paleogeographical profiles from North Kyushu to Southwestern Yamaguchi Prefecture.

Cenomanian

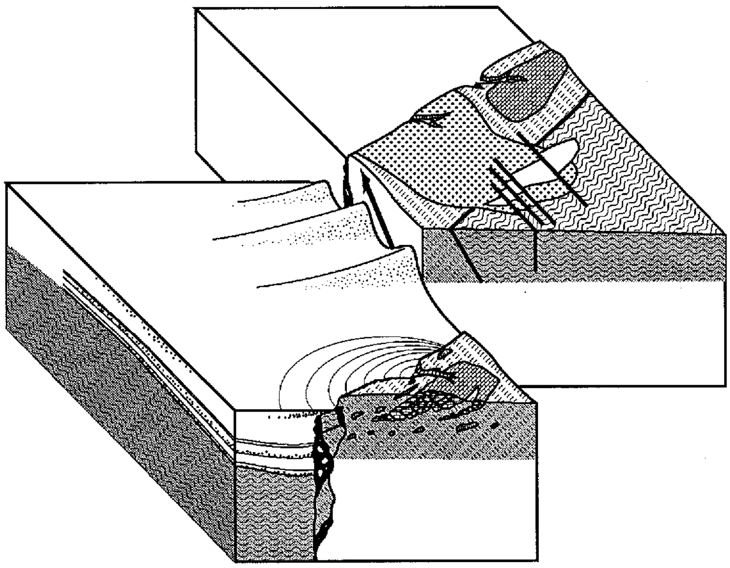


Fig. 42. Schematic paleogeographical profiles from North Kyushu to Southwestern Yamaguchi Prefecture.

Table 1. Clast components in the conglomerate.

			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	●			●		●	●	●			

Table 2. Division of sedimentary facies and interpreted depositional environment of the Toyonishi and Kanmon Groups.

Facies code	Facies	Sedimentary Structures	Environments
Gms	massive, matrix supported conglomerate	grading	debris flow deposits
Gm	massive or crudely bedded conglomerate	horizontal bedding, imbrication	longitudinal bars, channel floor, lag deposits
Gp	conglomerate, stratified	planer cross beds	longitudinal bars
St	sandstone, medium to very coarse, may be pebbly	solitary or grouped trough cross beds	dunes (lower flow regime)
Sp	sandstone, medium to very coarse, may be pebbly	solitary or grouped planer cross beds	linguoid, transverse bars, sand waves (lower flow regime)
Sh	sandstone, very fine to very coarse	horizontal lamination parting or streaming lineation	planer bed flow (upper flow regime)
Sc	sandstone, fine to very coarse	massive, normal grading	crevasse splay
Sw	sandstone, fine to medium	massive with brackish molluscs	washover fan or flood tida delta
Fb	mudstone, siltstone, sandstone very fine to medium	massive with brackish molluscs	lagoon
Fl	sandstone, siltstone, mudstone	fine lamination, very small ripples	flood plain
Fr	mudstone, siltstone	pure-red to magenta in colore bioturbation	flood plain in arid and high temperature climate
Fc	mudstone, siltstone	calcretes	soil with chemical precipitation

Appendix 1. Clast components of the Lower Wakamiya Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	medium SS	86	50	51	fine SS	36	18
2	medium SS	20	10	52	quartzite	22	14
3	fine SS	14	8	53	medium SS	50	34
4	medium SS	30	14	54	coarse SS	36	24
5	mudstone	32	16	55	fine SS	48	28
6	fine SS	28	18	56	mudstone	32	8
7	medium SS	32	14	57	medium SS	50	26
8	fine SS	24	16	58	fine SS	60	24
9	chert	16	12	59	quartzite	22	14
10	fine SS	32	24	60	medium SS	62	28
11	medium SS	48	44	61	chert	28	16
12	medium SS	102	32	62	medium SS	34	20
13	chert	16	8	63	fine SS	50	18
14	medium SS	14	12	64	chert	28	18
15	fine SS	58	18	65	coarse SS	92	80
16	chert	14	8	66	fine SS	30	20
17	coarse SS	52	36	67	fine SS	43	30
18	chert	36	16	68	medium SS	34	16
19	fine SS	74	24	69	coarse SS	40	26
20	coarse SS	64	36	70	chert	42	28
21	coarse SS	44	22	71	chert	66	60
22	fine SS	56	42	72	medium SS	44	32
23	fine SS	84	84	73	fine SS	24	12
24	chert	18	16	74	chert	12	8
25	medium SS	28	16	75	fine SS	22	10
26	fine SS	56	18	76	medium SS	48	26
27	medium SS	86	54	77	quartzite	26	14
28	fine SS	28	16	78	medium SS	40	12
29	medium SS	38	36	79	quartzite	20	12
30	quartzite	53	46	80	medium SS	36	14
31	fine SS	56	32	81	medium SS	38	24
32	fine SS	88	30	82	fine SS	44	24
33	medium SS	98	30	83	fine SS	24	14
34	fine SS	24	14	84	quartzite	24	8
35	fine SS	26	18	85	chert	104	72
36	medium SS	78	66	86	medium SS	124	58
37	medium SS	28	14	87	chert	84	46
38	coarse SS	32	22	88	coarse SS	36	32
39	chert	12	8	89	medium SS	84	22
40	fine SS	28	18	90	medium SS	82	34
41	medium SS	72	38	91	chert	34	20
42	chert	18	8	92	coarse SS	94	70
43	medium SS	46	32	93	chert	30	14
44	fine SS	22	12	94	medium SS	62	38
45	medium SS	38	24	95	medium SS	50	48
46	mudstone	26	8	96	fine SS	32	20
47	medium SS	70	64	97	fine SS	22	12
48	chert	20	18	98	medium SS	48	16
49	coarse SS	68	50	99	medium SS	90	46
50	mudstone	54	20	100	fine SS	24	22

SS=Sandstone

Appendix 2. Clast components of the Shiohama Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	chert	36	18	51	fine SS	28	24
2	medium SS	30	18	52	chert	30	14
3	medium SS	34	24	53	chert	32	18
4	chert	36	20	54	fine SS	55	34
5	chert	60	38	55	medium SS	56	38
6	chert	20	14	56	coarse SS	74	35
7	medium SS	26	16	57	chert	2	16
8	medium SS	78	34	58	chert	24	14
9	chert	27	17	59	chert	30	24
10	medium SS	34	14	60	fine SS	62	54
11	medium SS	20	18	61	fine SS	40	19
12	fine SS	30	28	62	fine SS	40	33
13	chert	18	16	63	fine SS	36	18
14	medium SS	41	17	64	chert	24	18
15	coarse SS	24	17	65	medium SS	45	34
16	fine SS	20	17	66	medium SS	105	90
17	andesite	35	15	67	chert	27	24
18	fine SS	55	15	68	schist	35	24
19	chert	90	86	69	fine SS	40	20
20	fine SS	38	20	70	andesite	55	40
21	fine SS	26	17	71	andesite	130	100
22	chert	15	14	72	chert	80	50
23	andesite	30	17	73	fine SS	60	54
24	andesite	28	16	74	fine SS	23	15
25	fine SS	34	10	75	schist	25	24
26	chert	20	16	76	fine SS	34	14
27	fine SS	41	22	77	fine SS	38	20
28	fine SS	20	12	78	medium SS	34	20
29	schist	24	12	79	medium SS	40	22
30	schist	30	22	80	coarse SS	34	20
31	medium SS	80	57	81	medium SS	50	35
32	fine SS	31	14	82	schist	16	14
33	schist	47	25	83	fine SS	30	28
34	fine SS	38	20	84	medium SS	29	18
35	fine SS	31	22	85	medium SS	36	19
36	chert	42	40	86	schist	74	41
37	chert	35	18	87	schist	60	40
38	chert	42	14	88	andesite	130	80
39	fine SS	20	17	89	coarse SS	86	54
40	coarse SS	20	14	90	chert	52	26
41	fine SS	50	20	91	medium SS	32	28
42	chert	24	8	92	medium SS	34	18
43	schist	25	6	93	fine SS	80	30
44	andesite	46	28	94	chert	80	40
45	fine SS	32	12	95	schist	56	14
46	andesite	66	55	96	chert	40	21
47	fine SS	38	30	97	schist	55	20
48	chert	27	18	98	andesite	70	43
49	mudstone	44	10	99	andesite	34	32
50	andesite	46	42	100	coarse SS	42	34

SS=Sandstone

Appendix 3. Clast components of the Lowermost Sujigahama Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	mudstone	66	26	51	red shale	106	66
2	andesite	20	18	52	chert	38	16
3	mudstone	38	20	53	mudstone	40	30
4	fine SS	60	32	54	chert	40	28
5	andesite	104	60	55	chert	18	18
6	fine SS	38	18	56	fine SS	40	22
7	andesite	212	106	57	mudstone	66	14
8	andesite	70	44	58	andesite	20	18
9	andesite	94	64	59	andesite	56	22
10	fine SS	46	44	60	andesite	36	34
11	chert	16	12	61	andesite	104	76
12	chert	38	18	62	fine SS	68	46
13	andesite	42	22	63	andesite	84	28
14	fine SS	62	26	64	andesite	70	36
15	andesite	78	36	65	andesite	90	64
16	mudstone	108	32	66	schist	82	76
17	fine SS	26	18	67	fine SS	38	28
18	fine SS	26	24	68	fine SS	72	60
19	mudstone	114	20	69	mudstone	48	12
20	fine SS	176	82	70	mudstone	38	12
21	red shale	58	20	71	andesite	90	38
22	chert	12	10	72	andesite	74	42
23	fine SS	50	36	73	andesite	70	40
24	andesite	86	82	74	chert	24	26
25	andesite	110	84	75	andesite	64	18
26	chert	52	30	76	chert	26	18
27	fine SS	56	42	77	andesite	102	58
28	andesite	52	28	78	fine SS	80	38
29	fine SS	42	20	79	andesite	72	42
30	mudstone	62	24	80	andesite	40	36
31	red shale	64	30	81	andesite	64	30
32	mudstone	100	56	82	mudstone	54	28
33	andesite	76	30	83	andesite	108	56
34	andesite	60	34	84	quartzite	26	18
35	medium SS	44	26	85	mudstone	68	46
36	andesite	108	46	86	fine SS	32	18
37	chert	106	70	87	mudstone	70	16
38	andesite	110	72	88	andesite	40	22
39	fine SS	82	66	89	fine SS	46	16
40	fine SS	44	30	90	andesite	128	76
41	red shale	76	34	91	andesite	106	70
42	andesite	86	40	92	mudstone	66	8
43	andesite	60	24	93	fine SS	66	24
44	fine SS	80	32	94	chert	42	30
45	chert	40	36	95	fine SS	42	22
46	andesite	90	66	96	andesite	106	64
47	fine SS	56	52	97	mudstone	64	28
48	mudstone	120	60	98	fine SS	50	26
49	red shale	114	36	99	chert	32	28
50	fine SS	142	76	100	andesite	146	130

SS=Sandstone

Appendix 4. Clast components of the Lower Sujigahama Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	andesite	76	56	51	fine SS	35	18
2	fine SS	50	34	52	medium SS	20	18
3	medium SS	37	32	53	chert	44	25
4	chert	34	28	54	fine SS	48	14
5	medium SS	32	20	55	fine SS	47	15
6	medium SS	50	40	56	andesite	100	70
7	medium SS	42	30	57	chert	60	30
8	andesite	58	38	58	andesite	75	40
9	andesite	60	20	59	fine SS	47	35
10	andesite	80	34	60	mudstone	90	26
11	fine SS	50	30	61	medium SS	40	22
12	andesite	45	26	62	chert	22	18
13	andesite	50	24	63	medium SS	70	30
14	fine SS	32	22	64	mudstone	50	28
15	fine SS	34	16	65	chert	24	20
16	medium SS	54	22	66	andesite	60	38
17	fine SS	44	26	67	medium SS	28	20
18	chert	34	15	68	andesite	60	60
19	chert	55	34	69	chert	30	18
20	medium SS	80	52	70	chert	44	22
21	fine SS	55	30	71	andesite	46	18
22	fine SS	58	26	72	chert	45	20
23	andesite	25	20	73	andesite	44	34
24	chert	32	26	74	fine SS	18	16
25	andesite	46	34	75	medium SS	30	18
26	fine SS	36	34	76	chert	60	80
27	chert	34	25	77	andesite	50	36
28	chert	25	2	78	mudstone	32	22
29	fine SS	24	18	79	fine SS	32	30
30	coarse SS	54	35	80	fine SS	32	15
31	chert	86	60	81	fine SS	70	55
32	fine SS	35	20	82	chert	100	54
33	fine SS	63	28	83	chert	80	60
34	coarse SS	90	56	84	andesite	100	20
35	andesite	75	40	85	fine SS	90	38
36	chert	110	65	86	medium SS	52	32
37	fine SS	38	22	87	medium SS	44	32
38	chert	96	50	88	medium SS	43	24
39	andesite	98	64	89	andesite	44	30
40	andesite	45	36	90	fine SS	70	46
41	andesite	104	65	91	chert	50	44
42	fine SS	64	40	92	fine SS	58	40
43	andesite	50	30	93	chert	28	24
44	andesite	65	56	94	fine SS	28	23
45	chert	42	32	95	medium SS	80	62
46	andesite	165	128	96	medium SS	45	20
47	andesite	70	50	97	andesite	44	22
48	andesite	70	50	98	andesite	58	44
49	andesite	120	58	99	chert	32	24
50	andesite	50	36	100	andesite	170	80

SS=Sandstone

Appendix 5. Clast components of the middle Sujigahama Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	andesite	160	60	51	fine SS	34	16
2	chert	122	40	52	red shale	84	44
3	fine SS	24	22	53	fine SS	30	18
4	fine SS	26	22	54	fine SS	30	14
5	fine SS	46	22	55	fine SS	24	12
6	fine SS	22	16	56	andesite	84	50
7	andesite	150	96	57	fine SS	52	24
8	chert	34	16	58	chert	24	12
9	fine SS	36	20	59	fine SS	30	16
10	chert	36	18	60	chert	36	20
11	chert	28	22	61	fine SS	36	18
12	fine SS	30	26	62	fine SS	30	16
13	chert	22	22	63	mudstone	40	12
14	fine SS	60	38	64	chert	32	14
15	andesite	136	64	65	chert	70	28
16	andesite	130	64	66	andesite	50	36
17	chert	76	52	67	andesite	100	54
18	chert	30	20	68	fine SS	164	78
19	andesite	76	18	69	fine SS	64	46
20	andesite	56	44	70	chert	106	80
21	fine SS	60	40	71	chert	56	54
22	red shale	28	16	72	coarse SS	102	84
23	andesite	86	50	73	fine SS	30	22
24	chert	40	32	74	andesite	90	74
25	andesite	136	56	75	chert	22	22
26	chert	36	14	76	fine SS	30	22
27	fine SS	48	46	77	fine SS	60	18
28	andesite	120	54	78	andesite	44	22
29	coarse SS	116	48	79	fine SS	44	32
30	andesite	106	54	80	chert	64	50
31	andesite	36	20	81	fine SS	64	32
32	fine SS	16	10	82	mudstone	30	12
33	fine SS	52	24	83	red shale	50	20
34	andesite	114	48	84	fine SS	110	92
35	andesite	166	134	85	fine SS	54	30
36	fine SS	92	64	86	fine SS	100	74
37	chert	24	14	87	coarse SS	98	76
38	chert	50	26	88	fine SS	34	28
39	coarse SS	170	126	89	fine SS	46	36
40	fine SS	50	20	90	fine SS	36	24
41	andesite	106	68	91	andesite	50	36
42	fine SS	56	32	92	fine SS	60	34
43	fine SS	34	30	93	fine SS	38	26
44	chert	64	42	94	fine SS	44	26
45	fine SS	80	62	95	fine SS	60	32
46	coarse SS	174	110	96	andesite	70	40
47	fine SS	26	26	97	andesite	72	22
48	fine SS	46	28	98	chert	36	34
49	chert	40	36	99	fine SS	47	28
50	chert	36	14	100	chert	30	22

SS=Sandstone

Appendix 6. Clast components of the upper Sujigahama Formation.

No.	Clast Type	a axis	b axis (mm)	No.	Clast Type	a axis	b axis
1	chert	120	90	51	schist	24	18
2	chert	37	30	52	andesite	26	20
3	andesite	85	48	53	fine SS	30	24
4	chert	60	40	54	andesite	42	24
5	medium SS	52	22	55	chert	66	30
6	andesite	100	70	56	chert	42	24
7	andesite	40	18	57	rhyolite	85	66
8	medium SS	32	22	58	andesite	46	24
9	chert	38	20	59	fine SS	40	35
10	medium SS	32	20	60	chert	30	24
11	medium SS	32	16	61	chert	27	16
12	fine SS	56	40	62	chert	20	16
13	andesite	36	20	63	fine SS	20	18
14	chert	38	22	64	medium SS	40	22
15	medium SS	30	16	65	chert	50	28
16	chert	37	18	66	chert	22	22
17	medium SS	36	24	67	chert	42	20
18	chert	2	16	68	chert	42	28
19	andesite	44	26	69	chert	27	20
20	medium SS	30	16	70	chert	38	22
21	chert	40	30	71	andesite	36	20
22	chert	62	40	72	chert	35	25
23	andesite	38	26	73	fine SS	60	53
24	medium SS	26	20	74	chert	33	28
25	medium SS	28	20	75	chert	58	36
26	chert	70	52	76	chert	84	60
27	medium SS	22	18	77	medium SS	62	44
28	medium SS	32	20	78	medium SS	50	18
29	chert	50	20	79	chert	50	42
30	chert	34	20	80	medium SS	34	22
31	fine SS	35	14	81	andesite	144	32
32	fine SS	42	20	82	medium SS	55	24
33	andesite	64	28	83	medium SS	58	55
34	medium SS	46	32	84	chert	50	22
35	schist	28	8	85	medium SS	64	50
36	andesite	20	18	86	chert	30	28
37	chert	15	12	87	medium SS	55	52
38	chert	40	37	88	chert	64	56
39	andesite	32	22	89	chert	56	45
40	medium SS	30	20	90	chert	70	58
41	medium SS	28	18	91	chert	68	48
42	medium SS	84	45	92	andesite	40	24
43	andesite	42	30	93	fine SS	68	34
44	andesite	56	28	94	medium SS	78	38
45	chert	24	20	95	medium SS	45	32
46	medium SS	34	20	96	medium SS	90	70
47	chert	45	28	97	chert	100	46
48	chert	37	17	98	medium SS	88	43
49	chert	30	20	99	medium SS	45	22
50	schist	26	24	100	medium SS	86	70

SS=Sandstone