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End-Permian Convergent Zone along the Northern Margin of Kurosegawa Landmass and its Products in Central Shikoku, Southwest Japan

Yukio ISOZAKI*

(With 32 Figures and 9 Tables)

Abstract

The northern subbelt of the Chichibu Belt, Southwest Japan, retains records of tectonic evolution of the Late Paleozoic and Mesozoic ocean basin developed on the north of the ancient Kurosegawa Landmass (arc or microcontinent). The pre-Cretaceous edifice of this subbelt is composed of two tectono-stratigraphic units, namely the Paleozoic Complex (latest Permian) just on the north of the Kurosegawa Tectonic Zone and the Mesozoic Complex (Jurassic) in the northern half of the subbelt.

The Paleozoic Complex consists of Shingai Formation, "Shirakidani Group", Gonyu Formation and Agekura Formation, which are most reasonably explained as products in and around a convergent plate boundary along the northern margin of the ancient Kurosegawa Landmass in the end of Permian time. These formations are mixtures of land-bound rocks and oceanic ones, which were primarily isolated from each other. For example, sandstone, limestone conglomerate (rich in terrigenous clastics) and exotic blocks of granitic rocks and greenschist are regarded to have been emplaced along the ancient Kurosegawa Landmass. On the other hand, reefy limestone, limestone conglomerate (free from terrigenous clastics), greenstones and chert are suggested to have formed in the midst of an ocean under pelagic conditions. Acidic tuff and siliceous mudstone were probably accumulated in an oceanic regime rather closer to a convergent plate boundary than the former oceanic rocks. Acidic tuff is supposed to have been transported aerially from arc-related land areas and finally deposited in an oceanic realm. Mixing site of these kinds of rocks can be compared with trench and its environs in modern convergent plate boundaries, where land-bound rocks and oceanic ones can encounter and be mixed together. Olistostrome of the Shingai Formation and Unit II of the "Shirakidani Group" are interpreted as debris flow deposits emplaced in base-of-slope environments, probably in subduction zones. On the other hand, tectonic slices of the "Shirakidani Group" can be regarded as imbricated tectonic wedges formed through underplating and/or off-scraping processes in subduction zones. In addition, up-sequence gradual increment of terrigenous clastics in those pelagites alludes that their sites of deposition gradually approached land areas until their final arrival at a subduction zone.

Permian conglomerate-bearing formations in the Outer Zone of Southwest Japan are classified into two types, i.e. Shingai-type and Kuma-type. On the basis of their lithologic characters, formations of the former type are regarded as deposits in trench or lower slope basins, while the latter type ones as those in upper slope basins or fore-arc basins in arc-trench systems.

The Mesozoic Complex is also regarded as a subduction-related product of Jurassic time, well after the formation of the Paleozoic Complex in the far south. Thus in the closing history of the Northern Chichibu Basin in Late Paleozoic to Mesozoic time, at least two major tectonic phases

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are discriminated, i.e. one in the end of Permian and the other in Jurassic. Final closure of the Northern Chichibu Basin was accomplished through the collision of the Kurosegawa Landmass against the Asian Continent (Sino-Korean Landmass) at the end of Jurassic time, consuming the Mesozoic oceanic plate between them. Consequently, the Paleozoic Complex together with the Kurosegawa Landmass was accreted to the Asian continental margin as an allochthonous terrane and juxtaposed with the Mesozoic Complex.

CONTENTS

I. Introduction

Tectonic evolution of major orogenic belts in the world, characterized by complicated admixture of oceanic and continental materials, have been re-interpreted repeatedly in terms of ancient plate interactions between oceans and continents (e.g. Hamilton, 1969; Hsü, 1971). Especially, horizontal mass accretion from ocean side toward continent is regarded as the most important and essential aspect of both ancient orogenic belts and modern convergent plate boundaries. The proposal of suspect terranes (e.g. Jones *et al.*, 1977; Coney *et al.*, 1980), for example, may be an extreme expression of such understandings.

In reconstructing the tectonic framework and processes of ancient orogenies in comparison with modern analogues, it is at first required to reveal roots of individual rocks, viz. primary depositional environments of sedimentary rocks or geologic conditions of birthplaces of igneous and metamorphic rocks. In the latest decade the actual spacio-temporal distribution of ancient rocks has been revealed by utilization and amelioration of some effective researching methods, such as detailed age determination by means of radiolarian fossils and reliable measurement of paleomagnetism.

Concerning studies on the pre-Cretaceous geotectonics in Southwest Japan, the year of 1980 was a remarkable milestone, when stimulative data of radiolarian biostratigraphy began to pour out explosively (e.g. YAO *et al.*, 1980; MIZUTANI *et al.*, 1981; NAKASEKO (ed.), 1982). Combined with recognition of chaotic complexes often called olistostrome or mélange, new and numerous findings of radiolarians have revealed that the so-called Paleozoic (pre-Cretaceous) formations in Southwest Japan are complicated admixtures of various rocks of different origins. Especially, intimate juxtaposition of land-bound rocks and oceanic ones implies their horizontal mixing in ancient land/ocean boundaries. Pre-Cretaceous formations in the northern subbelt of the Chichibu Belt, Outer Zone of Southwest Japan, are good representatives of such kind of chaotic complexes, which are regarded to have formed in ancient convergent plate boundaries.

In the central part of Kochi Prefecture, the northern subbelt of the Chichibu Belt shows its widest distribution north of the Kurosegawa Tectonic Zone. The pre-Cretaceous rocks of the eugeosynclinal rock assemblage in the Yasuba-Shirakidani area, north of Kochi City and Tosa-yamada Town were ,studied by several pioneers before the World War II (e.g. KOBAYASHI & IJIRI, 1936; YAMAUCHI & HIRATA, 1939). Later in 1950s and '60s, K. ICHIKAWA and his colleagues investigated this area and clarified significant facts with special reference to the tectonic event in Late Permian to Middle Triassic age (e.g. ICHIKAWA *et al.*, 1954, 1956; SUYARI, 1961). Since then, the Yasuba-Shirakidani area has been known as one of the classical fields in the geohistorical studies of the Chichibu Belt.

The present author investigated mainly the pre-Cretaceous formations of the Yasuba-Shirakidani area in order to clarify the primary configuration of depositional sites of various rocks, and to figure out their geotectonic evolution in Late Paleozoic to Mesozoic time. In addition to regional mapping, biostratigraphical research by means of conodonts and radiolarians was carried out on siliceous, argillaceous and calcareous rocks. Through sedimentological and petrographical studies, special attention was paid to elucidating the primary birthplaces of individual constituent rocks of these formations. Furthermore, secondary mixing sites and mixing processes of these various rocks of different origins are discussed in comparison with tectono-sedimentary phenomena observed in modern convergent plate boundaries.

As a consequence of the present study, the pre-Cretaceous rocks of the northern subbelt of the Chichibu Belt, not only in the study area but also in other parts in Shikoku Island, can be clearly divided into two tectono-stratigraphic units, i.e. the Paleozoic Complex in the southern half of the subbelt and the Mesozoic Complex in the northern half. This paper focuses mainly on the Paleozoic Complex, whose analysis offers profitable information on the end-Permian tectonism along the northern margin of the ancient Kurosegawa Landmass. In addition, the Mesozoic Complex in the northern subbelt in Kochi and Tokushima Prefectures is briefly dealt with for comparison. In the second last chapter, a new model for tectono-sedimentary evolution of the Northern Chichibu Basin in Late Paleozoic to Mesozoic time is offered with special attention to the geotectonic behavior of the Kurosegawa Landmass.

Acknowledgements: The present author wishes to express his sincere gratitude to Prof. Koichiro ICHIKAWA of Osaka City University for his kind supervision throughout this research and critical reading of this manuscript. Special thanks are due to Prof. Kametoshi KANMERA of Kyushu University, Dr. Shigenori MARUYAMA of Toyama University and Dr. Tetsuo MATSUDA of Osaka City University for their instructive comments from various aspects. The author is also indebted to Dr. Akira YAO, Dr. Wataru MAEJIMA of Osaka City University, Prof. Shigeki HADA and As. Prof. Shinichi YOSHIKURA of Kochi University and As. Prof. Kazuo KIMINAMI of Yamaguchi University for their joining in discussion in field and laboratory. In addition, the author expresses his gratitude for Prof. Kenichi ISHII of Kobe University, As. Prof. Yuji OKIMURA of Hiroshima University, Prof. Nobuo YAMAGIWA of Osaka Kyoiku University, Prof. Sumio SAKAGAMI of Chiba University and Prof. Kei MORI of Tohoku University for their identification of fossils.

II. Outline of Geology

The Chichibu Belt in the Outer Zone of Southwest Japan extends approximately in E-W direction, occupying a narrow zone between the Sanbagawa Belt, on the north, and the Shimanto Bęlt, on the south (Fig. 1). In the central part of Kochi Prefecture, the Chichibu Belt is typically divided further into the northern, the middle and the southern subbelts that run parallel each other in E-W to ENE-WSW direction, on the basis of their difference in lithofacies and structural style (e.g. ICHIKAWA *et al.*, 1953, 1956; NAKAGAWA *et al.*, 1959). Among them, the middle subbelt is characterized and discriminated from the rest by having the components of the Kurosegawa Tectonic Zone, which are

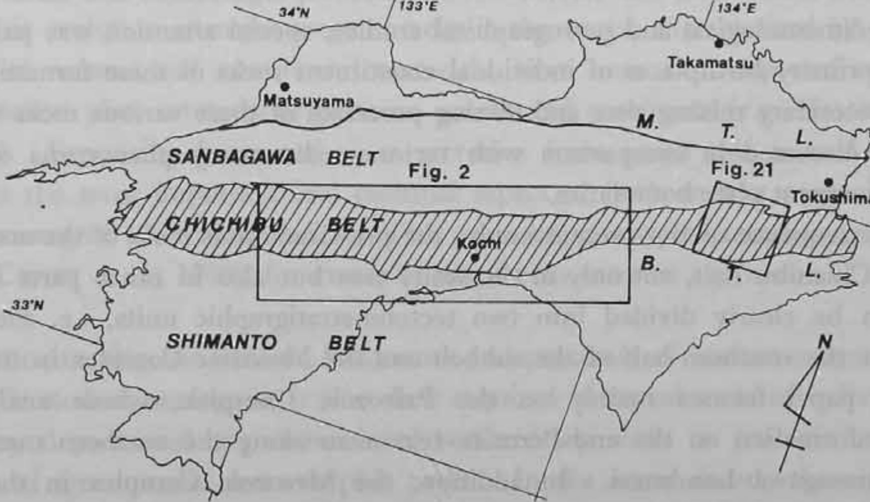


Fig. 1. Index map of the Chichibu Belt in Shikoku, Southwest Japan.

quite exotic in nature with respect to the proper rocks of the Chichibu Belt.

The northern subbelt is occupied by two newly discriminated tectono-stratigraphic units, namely the Paleozoic (end-Permian) Complex and the Mesozoic (Jurassic) Complex. The Paleozoic Complex is distributed in the southern half of the subbelt with close linkage to the Kurosegawa Tectonic Zone. The Mesozoic Complex, on the other hand, occupies northern half of the subbelt in intimate association with the Mikabu Greenstones and Sambagawa crystalline schists along its northen margin. These two complexes are bounded by a conspicuous fault, which is newly designated as the Agekura Thrust (Fig. 2) in this paper. The lateral extension of the Agekura Thrust is traceable throughout Kochi Prefecture.

The Yasuba-Shirakidani area, in the north of Kochi City and Tosa-yamada Town (Fig. 3), is underlain mainly by weakly metamorphosed pre-Cretaceous rocks and the Lower Cretaceous Ryoseki Group which covers the former unconformably. The wide zone of serpentinite in the southern margin of the area is regarded as eastern extension of the Konomori lenticular body (YOSHIKURA, 1985) of the Kurosegawa Tectonic Zone exposed in the midst of Kochi City.

Concerning the pre-Cretaceous rocks in the study area, the following five formations are discriminated on the basis of difference in lithologic characters (Fig. 3). From south to north, they are Gonyu Formation, Shingai Formation, "Shirakidani Group", Agekura Formation and Kamiyakawa Formation. The first four formations correspond to the Paleozoic Complex formed in the end-Permian tectogenesis, while the Kamiyakawa Formation belongs to the Mesozoic Complex shaped in the Jurassic event.

The Paleozoic formations are separated from each other by faults dipping north at rather high angle. Small serpentinite bodies intervene between those units. The tectonically overlying Mesozoic Kamiyakawa Formation partially covers these Paleozoic units along the Agekura Thrust.

In the eastern part of the area, Lower Cretaceous shallow-water sediments, the Ryoseki Group, are widely distributed, covering unconformably the Gonyu and the Shingai Formations. The unconformity between red chert of the Gonyu Formation and Cretaceous conglomerate has been well known as the Tengudake Unconformity (KOBAYASHI & IJIRI, 1936).

III. Paleozoic Complex

Lithologic characters of the formations of the Paleozoic Complex in the Yasuba-Shirakidani area, namely Shingai Formation, "Shirakidani Group" (Unit I and Unit II), Gonyu Formation and Agekura Formation, are described in this chapter. Biostratigraphical data and structural features of these formations will be given separately in following chapters.

1. Shingai Formation

A. Designation

The Shingai Formation was formerly called the Yasuba Formation (HASHIMOTO,

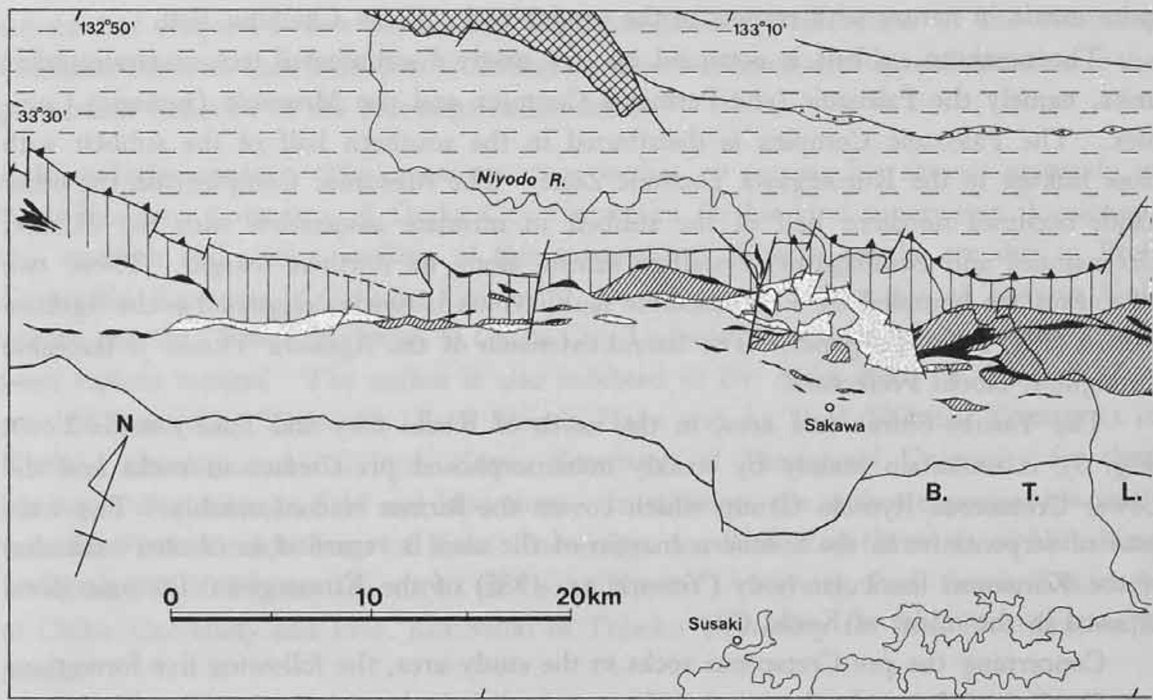


Fig. 2. Distribution of the Paleozoic and the Mesozoic Complexes in Central Shikoku. Compiled from KATTO *et al.* (1961, 1977), IKUMA (1980), ISOZAKI (1985), SUNOUCHI *et al.* (1982),

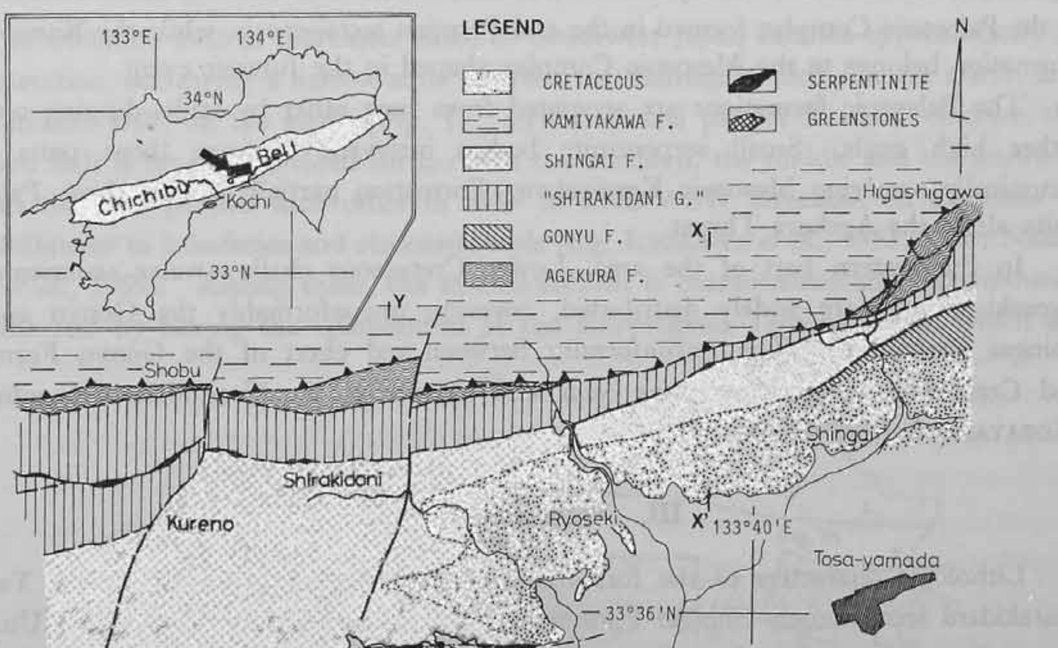
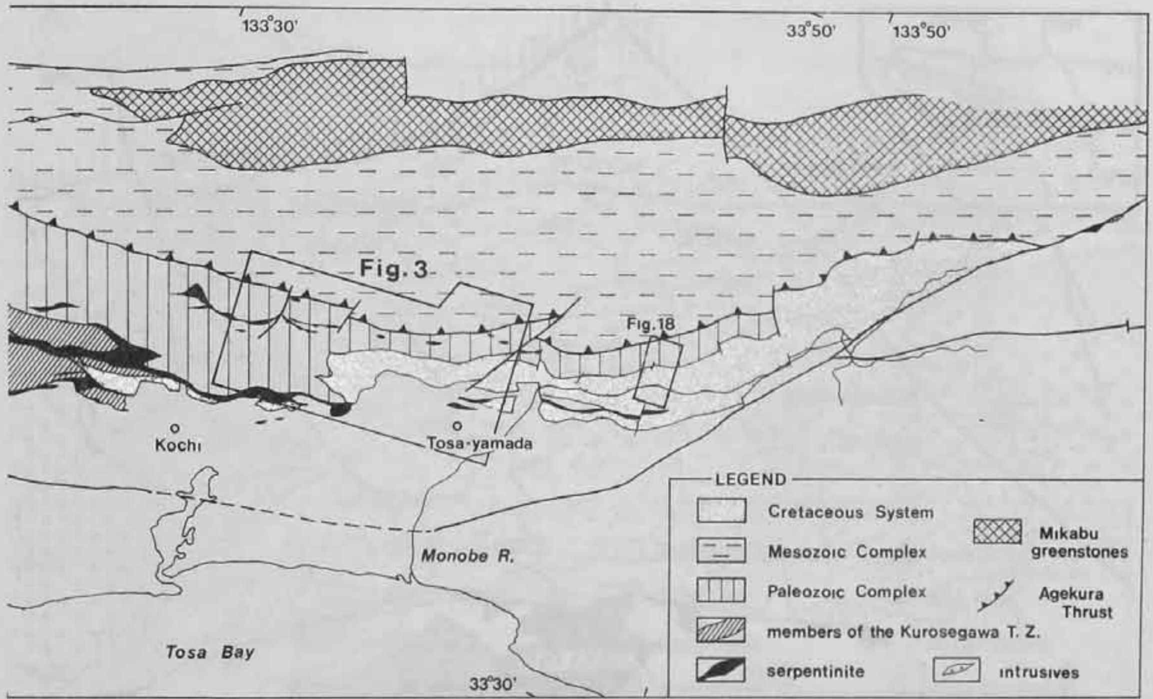


Fig. 3. Index and simplified geologic map of the Yasuba-Shirakidani area. Slightly modified from ISOZAKI (1985).

1955) because of its well-known constituent, Yasuba limestone conglomerate (TORIYAMA, 1942). On the basis of fusulinids from the Yasuba conglomerates (TORIYAMA, 1942;



KATTO & KAWASAWA (1958), HASHIMOTO (1967), HADA *et al.*, (1985), KIMURA & HORIKOSHI (1959), ISHIZAKI (1962).

KANMERA, 1954), this formation has long been believed to be early Late Permian stratigraphic unit (ISHIZAKI, 1960; SUYARI, 1961). The Yasuba limestone conglomerates, however, have been recently revealed as allochthonous blocks secondarily contained in the formation (ISOZAKI, 1985). Under the circumstances, the author applies newly designated name, Shingai Formation, instead of formerly used Yasuba Formation in order to avoid misunderstanding as if the Yasuba conglomerates were autochthonous units of the formation.

B. Stratotype and Distribution

Stratotype: vicinity of Yasuba, Shingai village, Tosa-yamada Town (Fig. 4).

Distribution: This formation occurs as a long geologic body extending in E-W direction; the eastern end of its distribution is to the northeast of the Shingai railway station and the western end in the vicinity of Shiino Pass, north of Kochi City. In the western half of the study area, this formation crops out rather widely from Shirakidani and Kureno, to the north, to Okou and Osaka Pass, to the south. On the northern margin, the Shingai Formation is in fault contact with the "Shirakidani Group". Small serpentinite bodies are sporadically intercalated between them. Along the southern margin of the Shingai Formation, the Gonyu Formation is narrowly distributed in the eastern part of the study area, while in the western part, serpentinite crops out widely. These units are bounded from the Shingai Formation by high angle faults.

C. Thickness

Maximum thickness, approximately 1000 m, was measured along the route between

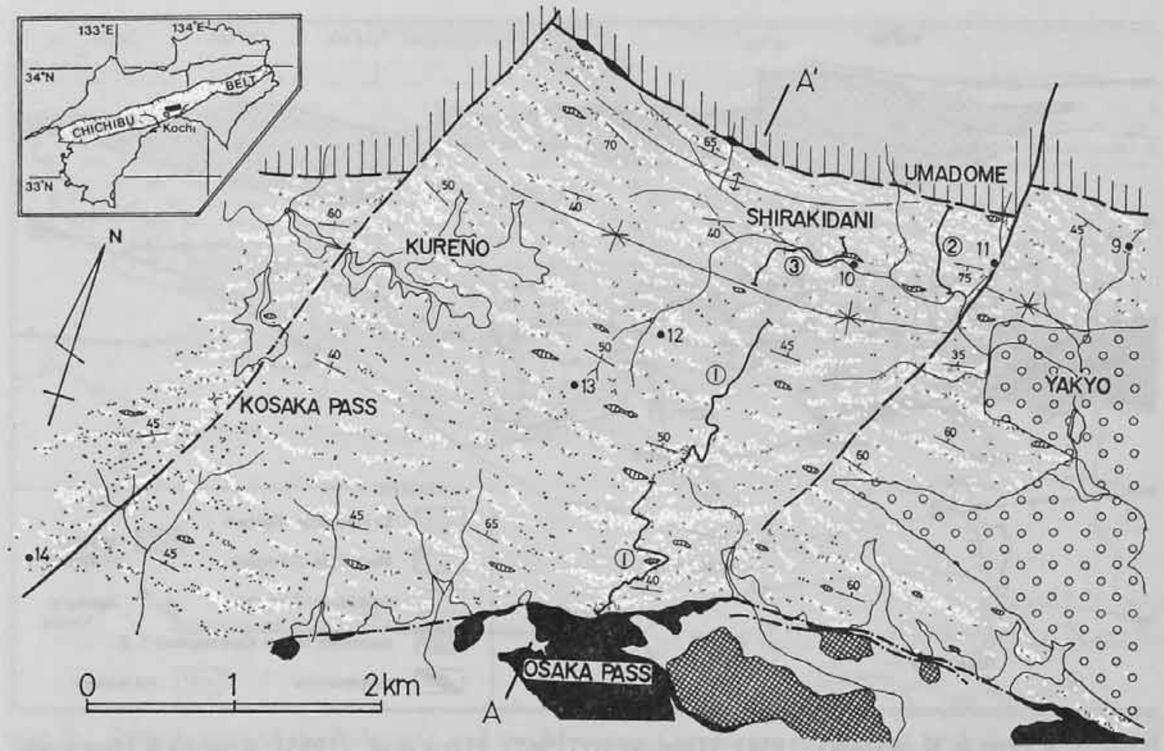


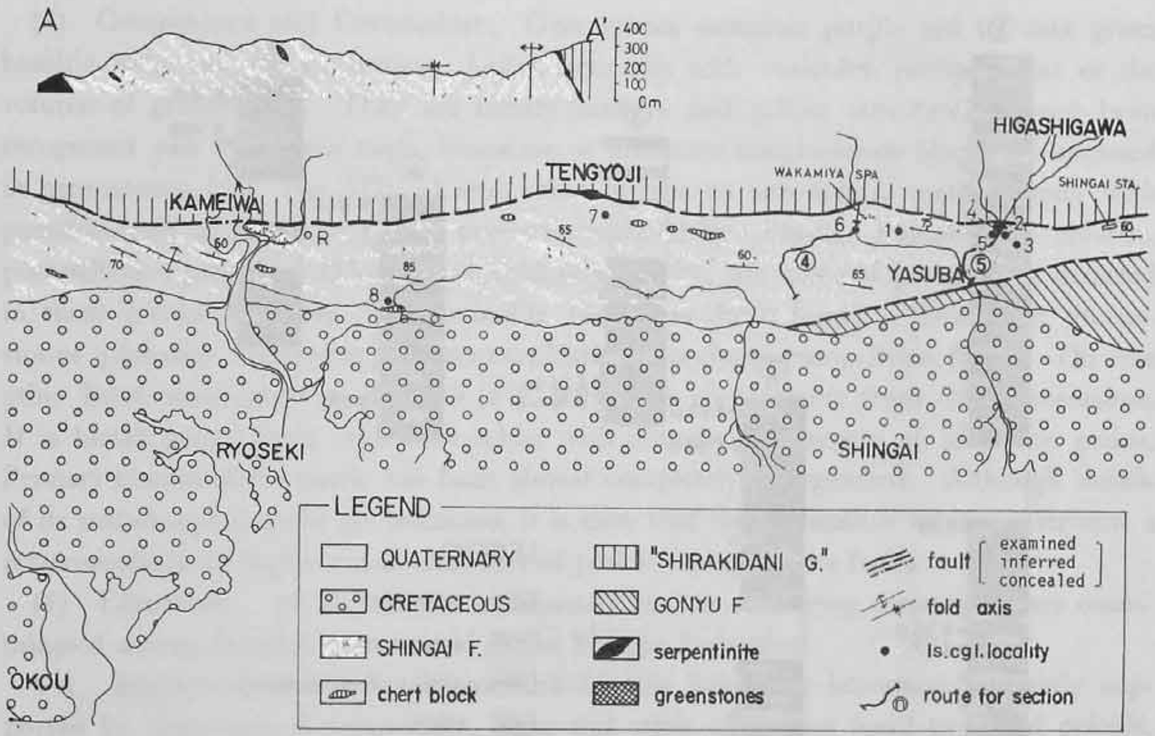
Fig. 4. Lithologic map of the Shingai Formation. After Isozaki (1985). Note following symbols for the Shingai Formation; Dotted area: sandstone dominant part of pebbly mudstone,

Shirakidani and Osaka Pass in the western part of the area, although tectonic repetition of the same stratigraphic portion by minor foldings has not been fully taken into account.

D. Stratigraphy and Lithology

(1) General Accounts: The Shingai Formation is composed mainly of mudstone and sandstone. Mudstone predominates in amount and contains abundant blocks and lenses of sandstone in various sizes (10 cm to several tens meter in diameter). In addition to sandstone, blocks and lenses of various sizes (pebble to 20 m in diameter) and lithologies, such as greenstones, limestone, limestone conglomerate, siliceous rocks and granitic rocks, are contained in pebbly mudstone. Mode of occurrence of these rocks indicates that they are exotic (allochthonous) masses, secondarily incorporated into mudstone matrices. As will be shown in following pages, various fossils of different ages, from Late Carboniferous to Late Permian, were obtained from these blocks. As they are scattered randomly in mudstone, apparent order of superposition shows no relation with primary ages of these blocks. Up to now, no in situ fossil has been recovered from the surrounding mudstone, which forms matrix of these blocks. Columnar sections of the Shingai Formation are given in Fig. 5. Further subdivision of the formation seems to be difficult because of olistostromal nature of the formation.

(2) Pebbly Mudstone: Ill-sorted black chaotic mudstones, with sporadically scattered clasts ranging from several millimeters to 1 cm in size, are called pebbly mudstone in this paper. Also sand grains are contained irregularly in ill-sorted argillaceous matrices of silt or finer size. Except for olistostromal chaotic features, no conspicuous sedimentary



solid circle: locality of conglomerate (Locs. 1–14).

structure, such as lamination or grading, has been recognized. Sedimentary characteristics of pebbly mudstone and mode of occurrence of exotic blocks, i.e. matrix-supported fabric, can be well compared to those of deposits transported by debris flows.

E. Exotic Blocks

Besides the most abundant sandstone blocks, various kind of exotic blocks are contained in the pebbly mudstone (Fig. 6). They are greenstones (basaltic lavas and volcaniclastics), greenschist, limestone (bioclastic/oolitic grainstone and wackestone, allodapic limestone), limestone conglomerate (Type I-III, see below), chert, acidic tuff, siliceous mudstone and granitic rocks.

(1) Mode of Occurrence: Generally, these exotic blocks form lenses or block-shaped bodies of several centimeters to 20 m in diameter. As mentioned before, sandstone predominates both in number and in volume among them. Chert and greenstones follow in the second place. Most of the larger blocks, more than 5 m in diameter, belong to one of these three lithologies. Blocks of the other lithologies are generally rather small.

Examples of mode of occurrence of these rocks are shown in Figs. 7, 8. Except for secondarily displaced contact with minor slip, most of the blocks are essentially enveloped within surrounding mudstone without having tectonic surface around them. In the case of blocks of sedimentary rocks, sharp truncation of bedding planes along the outer surface of the block can be observed. In the case of blocks of igneous or high-pressure metamorphic rock, there is no contact aureole nor remains of regional metamorphism in the surround-

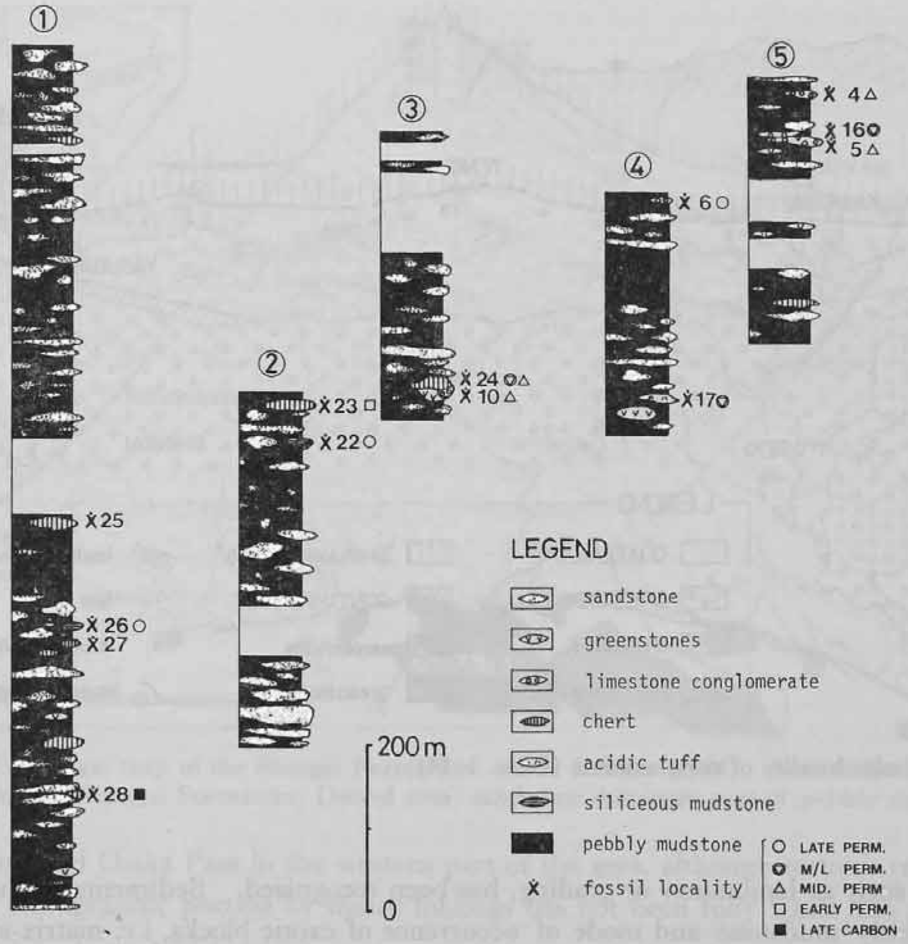


Fig. 5. Columnar sections of the Shingai Formation. Modified from ISOZAKI (1985). 1: north of Osaka Pass (southern limb of the syncline), 2: Umadome, 3: Shirakidani (northern limb of the syncline), 4: south of Wakamiya Spa, 5: Yasuba (northern limb of the anticline). For locations of the sections, see Fig. 4.

ing pebbly mudstone. Mineral parageneses recognized in greenstones of the Shingai Formation and neighbouring "Shirakidani Group" are mostly prehnite+pumpellyite+chlorite or pumpellyite+chlorite. Along these lines of evidence, it is obvious that those blocks are not in situ rocks in the surrounding mudstone, but are exotic in origin. Detailed description on individual lithologies of the exotic blocks is given below.

(2) Sandstone: Sandstones are generally massive and rarely interbedded with mudstone. Except for grading and cross-lamination rarely observed, no conspicuous sedimentary structure is recognized. They are mostly medium- to coarse-grained feldspathic arenite and wacke, composed mainly of feldspar, quartz and rock fragments of felsic to mafic igneous rocks. Also angular mudstone clasts of 1–2 mm in length are commonly contained. In addition, detrital hornblende, orthopyroxene, biotite, epidote and fragment of crystalline schist are rarely contained. Most of the grains are rather angular and ill-sorted.

(3) Greenstones and Greenschist: Greenstones comprise purple red to dark green basaltic lavas and volcaniclastics. Lavas, generally with vesicules, occupy most of the volume of greenstones. They are mostly massive and pillow structure has not been recognized yet. In some cases, limestone or limestone conglomerate blocks are enclosed in greenstones (e.g. Fig. 7D). Lavas show ophitic to sub-ophitic texture rarely with pseudomorph of olivine, which is presently replaced by chlorite. Pumpellyite+chlorite, pumpellyite+prehnite+chlorite and epidote+chlorite, are mineral parageneses detected in these greenstones (Fig. 9). Actinolite has never been found. Thus these greensstones probably underwent a metamorphism of prehnite-pumpellyite facies. On the other hand, greenschist at Loc. 39 (Fig. 10) differs considerably from other greenstone. It is bluish green fissile crystalline schist with abundant aggregate of lawsonite grains. Primary texture of the basite has been almost completely disorganized. Although details of its metamorphic grade are unknown, it is clear that this crystalline schist underwent a metamorphism of higher grade than that of prehnite-pumpellyite facies.

(4) Limestone: On the basis of sedimentary texture, following three types are discriminated among limestones contained in the Shingai Formation.

4–1. *bioclastic grainstone**; Framework of this light gray limestone is mainly supported by fragments of foraminifer, algae and other calcareous fossil tests and peloids, which are cemented with sparry calcite. Late Carboniferous to Early Permian conodonts, were also obtained. Intimate association with greenstones and similarity in lithofacies and fossil content indicate that this limestone is certainly correlated with limestone of Unit I of the "Shirakidani Group", which will be described in the next section.

4–2. *bioclastic wackestone**; Dark gray limestone contains abundant fragments of crinoid stems, which are supported by micritic matrix. Small bivalves of 5 mm or less in length also occur, but they are not adequately preserved for precise taxonomic identification. This limestone resembles micritic limestone clast contained in Type II limestone conglomerate, which will be described below.

4–3. *allodapic limestone*; Reddish gray well-bedded limestone occurs in close association with Type I limestone conglomerate, which shares common features with the limestone both in clast and matrix. This limestone can be described as bedded calcareous sandstone and mudstone, composed mainly of limestone fragments of clay to sand size with minor amount of greenstone clasts. They are completely free from detrital quartz. Matrix of sandstone part is fine-grained mafic volcaniclastics. Because sedimentary structures, such as grading or parallel and/or cross lamination, are features common with those of ordinary turbidites, this limestone corresponds to calcareous turbidite or allodapic limestone named by MEISCHNER (1964). Within limestone clasts, fragments of corals, smaller foraminifers and bryozoans are identified.

(5) Limestone Conglomerate: On the basis of differences in texture and composition, limestone conglomerates are classified into following three types as shown in Fig. 11. In

* Limestones are classified and named after DUNHAM (1962).

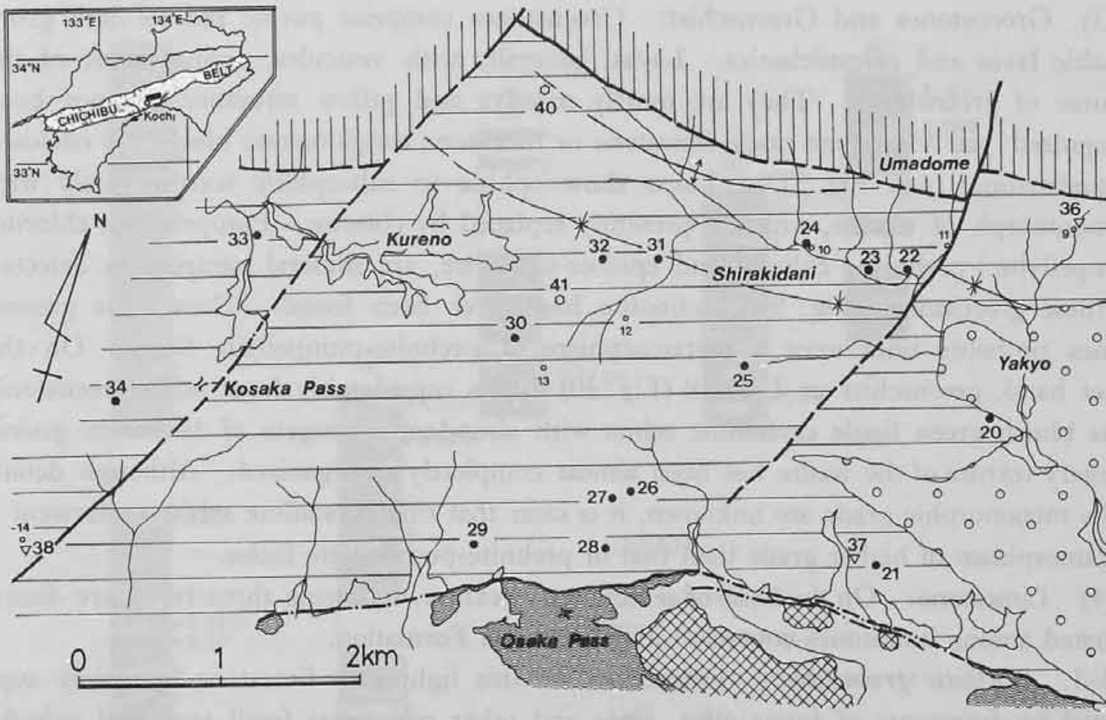


Fig. 6. Localities of exotic blocks in the Shingai Formation.

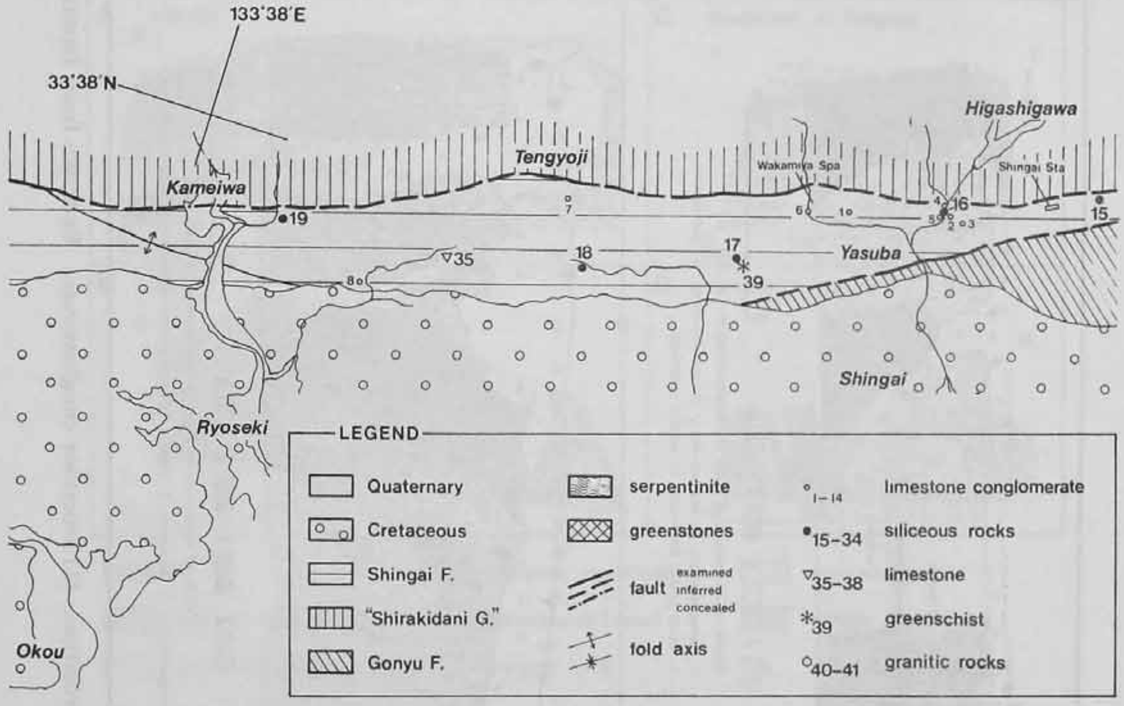
these conglomerates, limestone generally shares more than 50%, at least 10%, of all clasts.

5-1. *Type I conglomerate*; Limestone conglomerate of this type has clast-supported framework with matrix mainly composed of mafic volcaniclastics. Among clasts, limestone predominates both in number and volume. Greenstones are accessory in amount. Grain size of the clasts is generally small and varies from 5 mm to 5 cm. Clasts are mostly subangular and ill-sorted. Except recrystallized ones, most of the limestones are classified in bioclastic and/or oolitic grainstone with abundant fragments of corals, bryozoans, sponges, fusulinids, algaes, crinoids and other fossils.

No conspicuous sedimentary structures is recognized. In some cases, this limestone conglomerate accompanies allodapic limestone mentioned above. Neither clast nor matrix contains any single grain of coarse terrigenous clastic material.

5-2. *Type II conglomerate*; Limestone conglomerate of this type is characterized by clast-supported framework and matrix with abundant coarse-grained clastics. Besides limestone, clasts comprise greenstones (basaltic to andestic), gabbro, felsic to intermediate pyroclastics (tuff, tuff breccia), schist, mudstone and some others. Welded texture is often observed in acidic tuff. Gabbro resembles that of the Mitaki Igneous Rocks in the Kurosegawa Tectonic Zone. Among limestones, bioclastic packstone and wackestone are more common than bioclastic or oolitic grainstone. All kinds of the limestone clasts contain fossil fragments, such as fusulinids, smaller foraminifers, corals, bryozoans, algaes, stromatoporoids and crinoids.

Size of ill-sorted clasts varies from 5 mm to 5 cm with the maximum one over 30 cm in diameter. Compared with well-rounded clasts of acidic tuff and gabbro, limestone



After ISOZAKI (1986). For those of greenstones, see Fig. 9.

clasts are rather angular. Matrix of the conglomerate is calcareous sandstone which is composed mainly of quartz and plagioclase with minor amount of rock fragments. Except faint lamination, any significant sedimentary structure such as preferred orientation or grading has not been recognized yet.

5–3. *Type III conglomerate*; Clasts of this type of conglomerate, mostly smaller than 2 cm in diameter, are irregularly scatterd and supported by matrix. Calcareous mudstone or marl forms matrix of this conglomerate, sharing over 70% in volume. Among the clasts, limestone predominates in number and volume. An accessory amount of greenstones and mudstone is also contained. Limestones are classified into bioclastic grainstone (most common), packstone or wackestone, rich in fragments of fossils such as fusulinids, corals and bryozoans. No significant sedimentary structure is observed in conglomerates.

(6) Siliceous Rocks: As chert, acidic tuff and siliceous mudstone once formed a continuous stratigraphic sequence in ascending order, as will be mentioned later (Chapter VI, 3-C), these three are treated together as siliceous rocks henceforth in this paper.

6–1. *chert*; Pale green to greenish gray bedded chert is the most common among the siliceous rocks. Massive chert is rather rarely observed. Bedded chert is made up of rhythmically alternating siliceous layers of 2–5 cm thickness and siliceous mudstone films of 1–5 mm thickness. Inconspicuous parallel lamination is often observed in the siliceous layer. Sponge spicules, radiolarians and conodonts are abundantly contained. In some cases (e.g. Locs. 24, 34), close association with bedded acidic tuff and upward gradual change from chert to acidic tuff are examined.

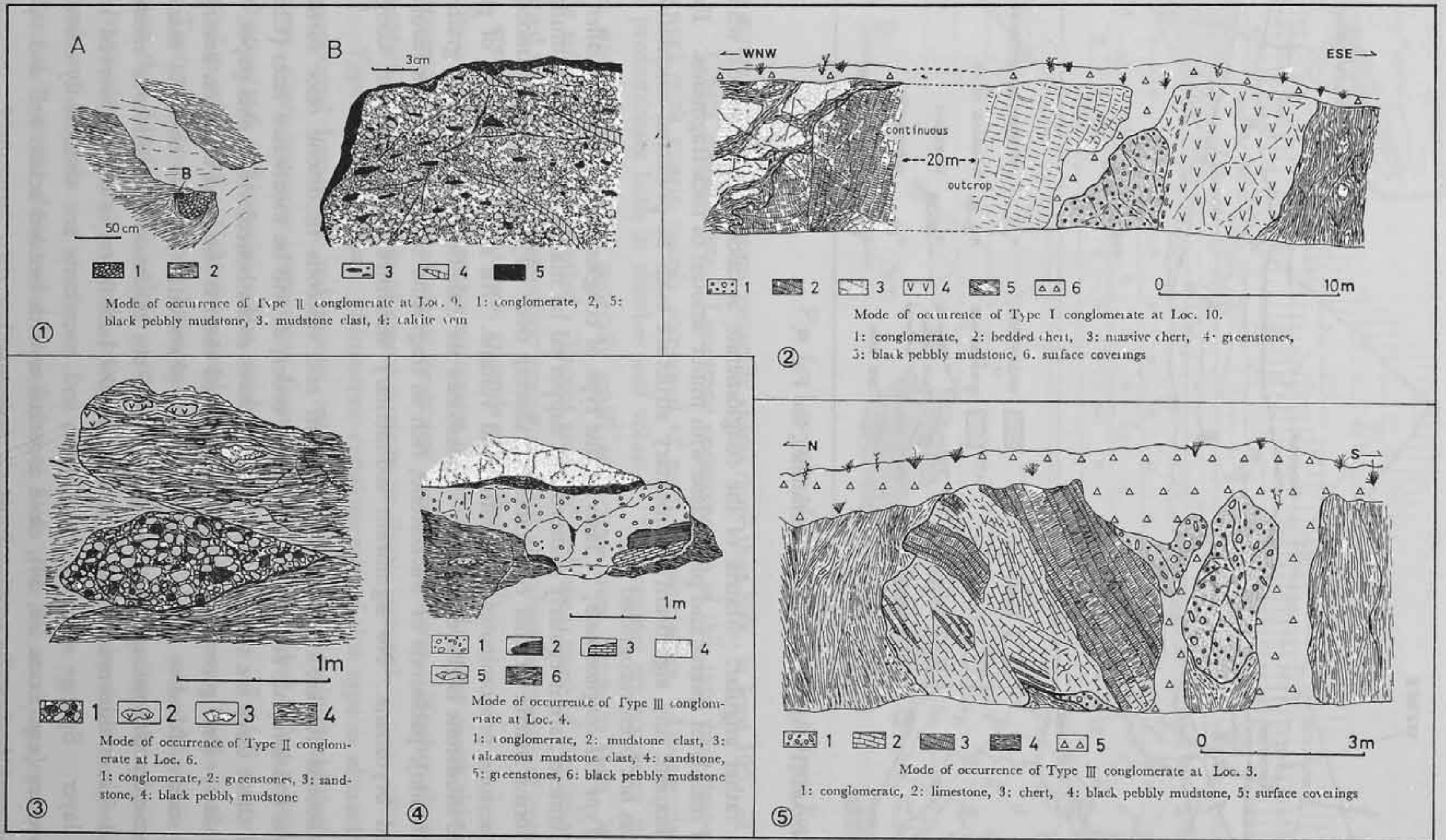


Fig. 7. Mode of occurrence of exotic blocks in pebbly mudstone of the Shingai Formation. (1) limestone conglomerate. Redrawn from ISOZAKI (1985). For their locations, see Fig. 6.

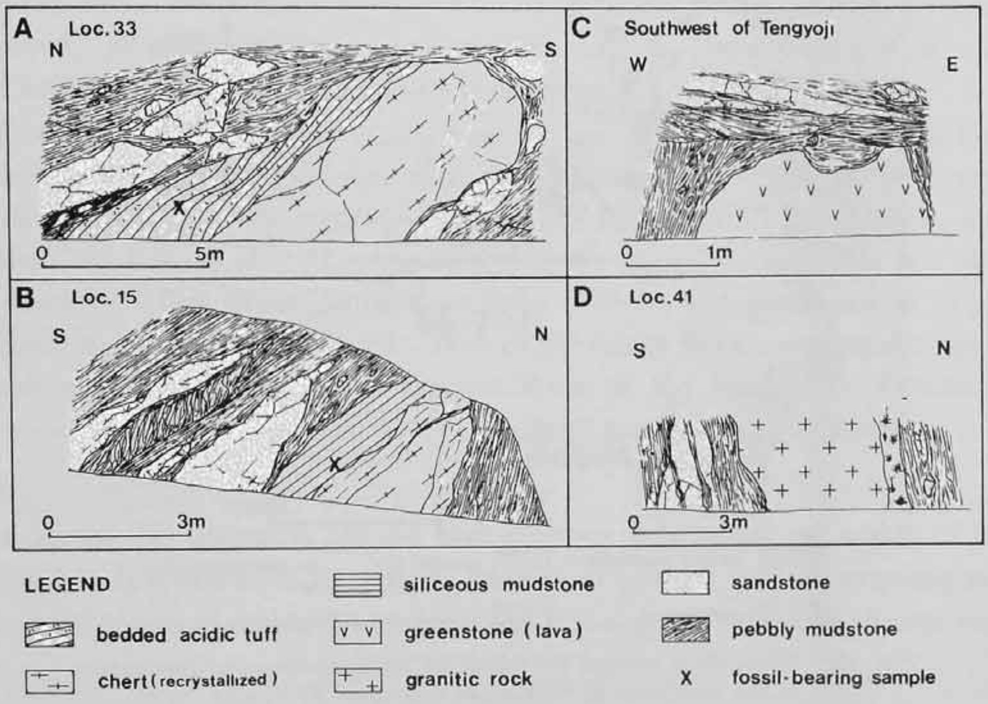


Fig. 8. Mode of occurrence of exotic blocks in pebbly mudstone of the Shingai Formation. (2) miscellaneous. After ISOZAKI (1986). For their locations, see Fig. 6.

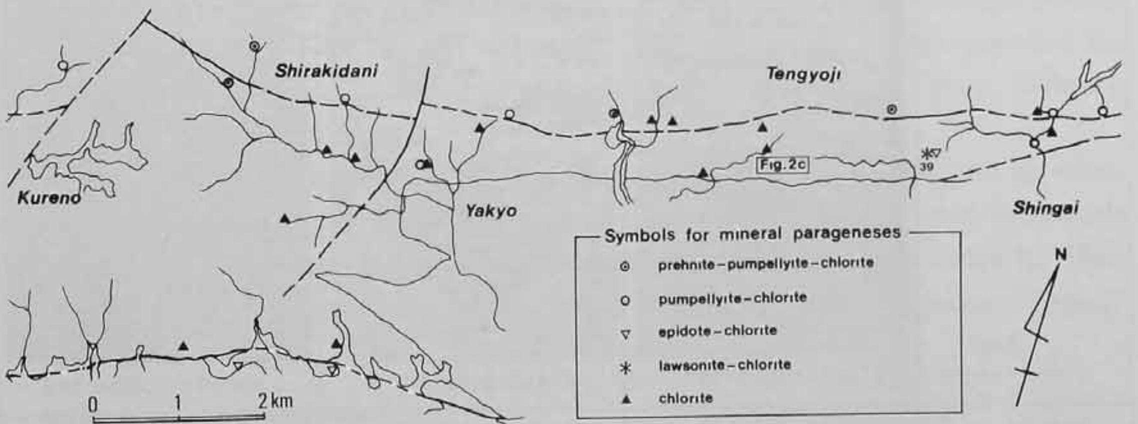


Fig. 9. Sample localities of greenstones of the Shingai Formation and the "Shirakidani Group", and their mineral parageneses (Mineral identification by S. MARUYAMA). After ISOZAKI (1986).

6–2. *acidic tuff*; Greenish gray acidic tuff is well-bedded and thickness of each layer is mostly 5–15 cm. Compared with chert, it shows less clear bedding. Most of the acidic tuff are almost free from crystals and rock fragments and they are generally classified into vitric tuff. Parallel lamination is well developed in every layer and grading is seldom observed. Sponge spicules, radiolarians and conodonts are obtained, but are not so abundant as in chert.

6–3. *siliceous mudstone*; Light gray siliceous mudstone is composed of well-sorted

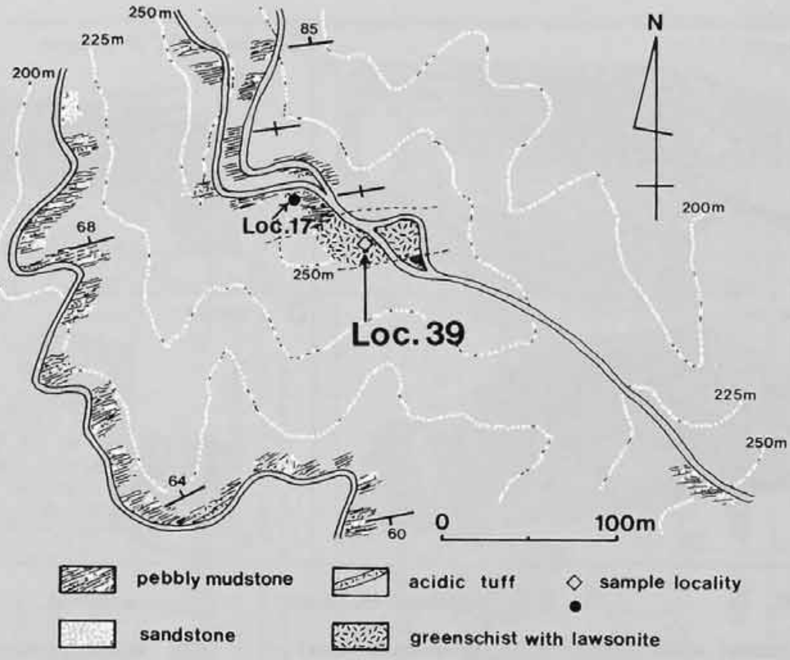


Fig. 10. Route-map around the block of lawsonite-bearing greenschist in the southwest of Wakamiya Spa (Loc. 39 in Figs. 6, 9).

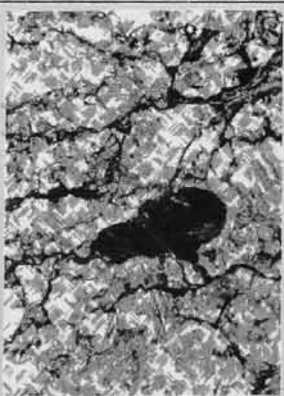
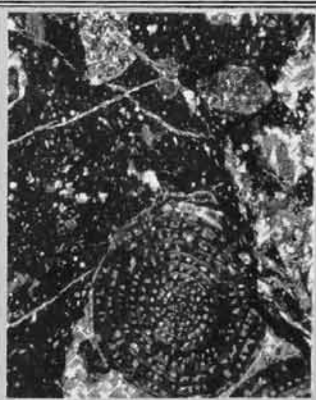
Type	I	II	III
Texture 2 mm	 clast-supported	 clast-supported	 matrix-supported
Matrix	mafic volcani- clastics	sandstone	calcareous mudstone
Clast	limestone (grainstone), greenstones	limestone (packstone, wackestone, grainstone), mafic-intermed. igneous rocks, felsic-intermed. pyroclastics	limestone (grainstone), greenstones
Fossil ages of clasts	Mid. Permian Early Permian	Late Permian Mid. Permian Early Permian	Mid. Permian Early Permian
Age	Early-Middle Permian	latest Permian or later	Early-Middle Permian

Fig. 11. Classification of limestone conglomerates of the Shingai Formation.

grains of clay size. Bedding is unclear but parallel lamination exaggerated by faint fissility is recognized. It yields radiolarians and sponge spicules. Intercalation of thin layers of acidic tuff, less than several centimeters is observed at Loc. 26.

(7) Granitic Rocks: Blocks of this type are detected at only two localities. At Loc. 40, mylonitic hornblende diorite occurs as block of 5 m in diameter. Because of extensively developed foliation, primary texture of diorite has been mostly destructed except for some parts. At Loc. 41 (Fig. 8D), hornblende biotite quartz diorite occurs as a block of 4 m in diameter. This diorite contains xenoliths of gneiss with pseudomorph of garnet. No conspicuous foliation was detected. Both of the diorite blocks mentioned above show remarkable similarity to the Mitaki Igneous Rocks of the Kurosegawa Tectonic Zone (Ichikawa *et al.* 1956; Yoshikura, 1977) in mineral composition and texture.

F. Age

The age of this formation has not been precisely determined yet, owing to lack of in situ fossils. It is conceived to be latest Permian or younger, but not so young as Late Triassic, on the basis of various lines of indirect evidences. For further details, see next chapter.

2. "Shirakidani Group"

A. Designation

Ishizaki (1960) firstly discriminated these rocks under the name of "Shingai Formation" from the surroundings. Soon after that, however, Suyari (1961) emended the stratigraphic content of this geologic unit and renamed it as Shirakidani Group, abandoning the former name*.

As described below, this "group" is composed of two units, Unit I and Unit II, which are not in stratigraphic relation but are intimately associated with each other as tectonic consequences. Characteristics of the two units are briefly summarized in Table 1. Here in this paper, they are tentatively grouped together in the name of the "Shirakidni Group" with quotation.

B. Stratotype and Distribution

Stratotype of Unit I: Kotaki Outcrop of the Shirakidani Quarry, Nangoku City (Fig. 12).

Stratotype of Unit II: Nyujo, Kureno village, northern part of Kochi City (Fig. 12).

Distribution: These units together with the Agekura Formation, occur in a narrow zone running in E-W direction between the Kamiyakawa Formation on the north and the Shingai Formation on the south. This zone extends from Higashigawa, Tosa-yamada Town on the east via Wakamiya Spa, Kameiwa, north of Shirakidani, Sasagatou to Hiraishi,

* Since the emendation by Suyari (1961), the name of the Shingai Formation has never been used in Ishizaki's sense. Therefore, the author believes that there would be no confusion in applying the same name, Shingai Formation, to another geologic entity.

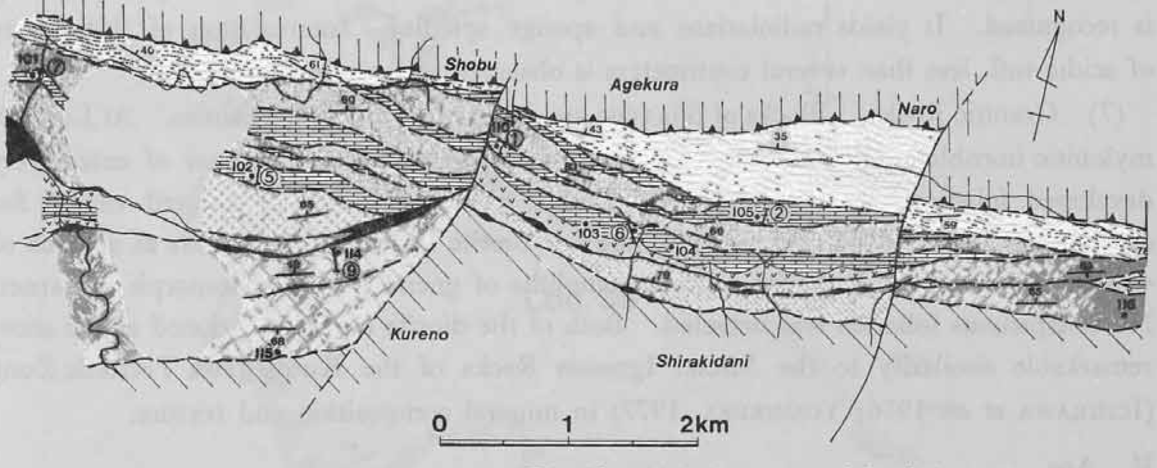


Fig. 12. Lithologic map of the "Shirakidani Group"

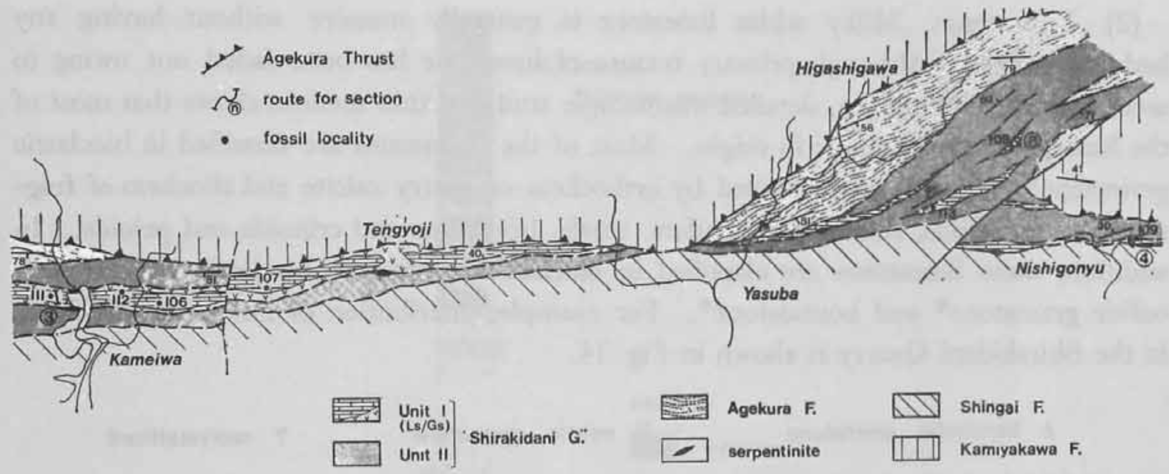
Table 1. Comparison between Unit I and Unit II of the "Shirakidani Group".

	Unit I	Unit II
Lithology	limestone (bioclastic and oolitic grainstone, boundstone) greenstones (basaltic lava and volcani-clastics)	olistostrome [matrix: mudstone (+sandstone) exotic blocks: greenstones, bedded chert, acidic tuff, sandstone
Fossils	fusulinids, rugose corals, conodonts (from limestone)	conodonts, radiolarians (from chert and acidic tuff)
Origin	organic reef or limestone mound developed on a volcanic seamount	debris flow deposits emplaced in trench environs
Age	Early-Mid. Permian	Late Permian —

Tosayama village on the west. Width of this zone varies considerably, from 0 to 2000 m, depending on the extent of the area covered by overriding nappe of the Kamiyakawa Formation.

C. Stratigraphy and Lithology of Unit I

(1) Stratigraphy: Unit I is composed of thick, white and massive limestone and greenstones, completely devoid of coarse-grained terrigenous clastics. Limestone predominates in volume, and is at least 150 m thick, while underlying greenstones are rather thin, no more than 50 m thick. Stratigraphic columns of Unit I are shown in Fig. 13. On the basis of biostratigraphic study on fusulinids, it is revealed that the limestone of



in the Yasuba-Shirakidani area, central Kochi Prefecture.

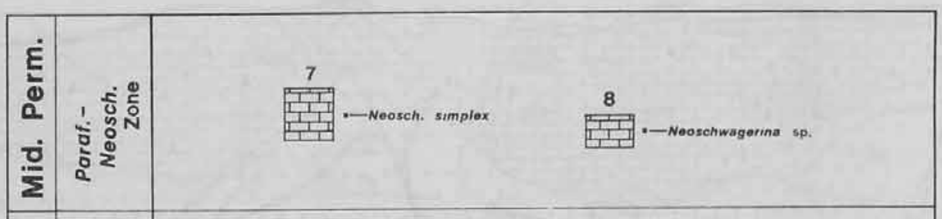


Fig. 13. Columnar sections of Unit I of the "Shirakidani Group". 1: west of Mt. Hosoyabu-yama, 2: Naro Quarry, 3: Kameiwa Quarry, 4: south of Ogonyu, 5: Sasagatou, 6: Shirakidani Quarry (Kotaki), 7: Tosa-yama, 8: southeast of Higashigawa. See Fig. 12 for their locations.

Unit I ranges from Early to Middle Permian (*Pseudoschwagerina* Zone to *Neoschwagerina* Zone). Continuous succession from Lower to Middle Permian, however, has not been ascertained yet, owing to later tectonic disruptions.

(2) Limestone: Milky white limestone is generally massive without having any bedding surface. Although primary texture of limestone has been faded out owing to secondary recrystallization, detailed microscopic study on thin sections shows that most of the limestones are bioclastic in origin. Most of the limestones are classified in bioclastic grainstone*, which is characterized by orthochem of sparry calcite and allochem of fragments of fusulinids, smaller foraminifers, corals, bryozoans and crinoids and peloids. In addition, some limestones are classified in bioclastic packstone*, bioclastic wackestone*, oolitic grainstone* and boundstone*. For example, distribution of limestone lithofacies in the Shirakidani Quarry is shown in Fig. 14.

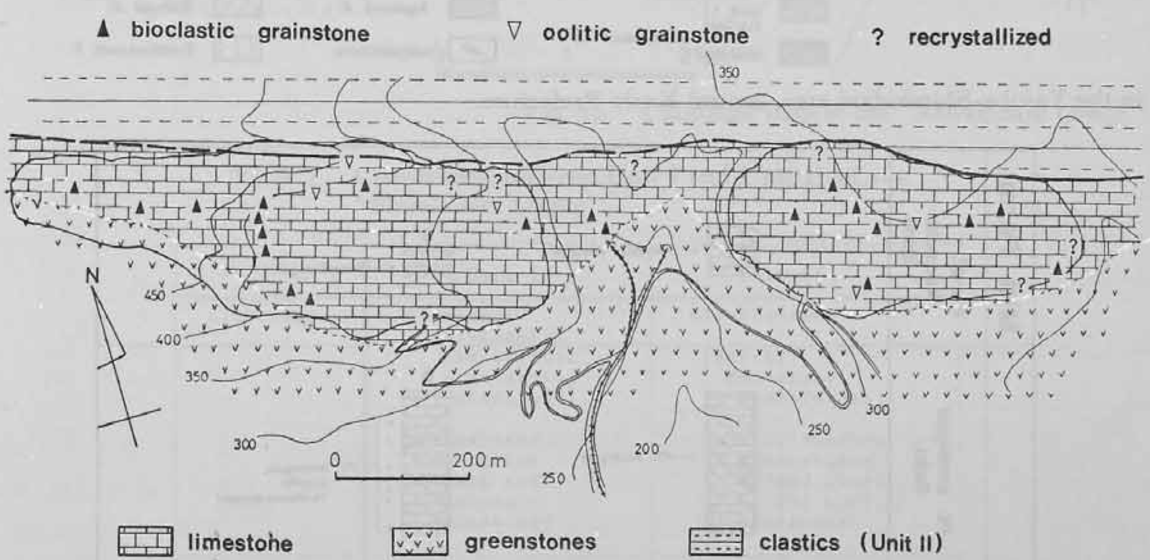


Fig. 14. Lithofacies of limestones of Unit I of the "Shirakidani Group" in the Shirakidani Quarry at Kotaki, Shirakidani (Fig. 12).

(3) Greenstones: Dark green to purple red greenstones are composed of basaltic lava and volcaniclastics. Pillow structure is commonly observed at the topmost horizon just below limestone. Pillows are usually 30–60 cm in diameter and bear vesicles. Small limestone blocks, less than 30 cm in diameter, are rarely contained in the volcaniclastics. Under microscope, ophitic to sub-ophitic texture and pseudomorph of pyroxene are detected in lavas, while in volcaniclastics, characteristic texture of volcanic glass is observed. Following two metamorphic mineral parageneses were examined (identified by S. MARUYAMA); prehnite+pumpellyite+chlorite, pumpellyite+chlorite.

D. Stratigraphy and Lithology of Unit II

(1) Stratigraphy: Unit II comprises mudstone, sandstone and greenstones with accessory amount of chert and acidic tuff. Clastics and greenstones roughly share halves of the total volume or the former exceeds by 10–20% in volume. Columnar section of this unit along Route ⑨ in Nyujo is given in Fig. 15. Thickness of this unit at the type locality is approximately 300 m.

* See footnote in page 61.

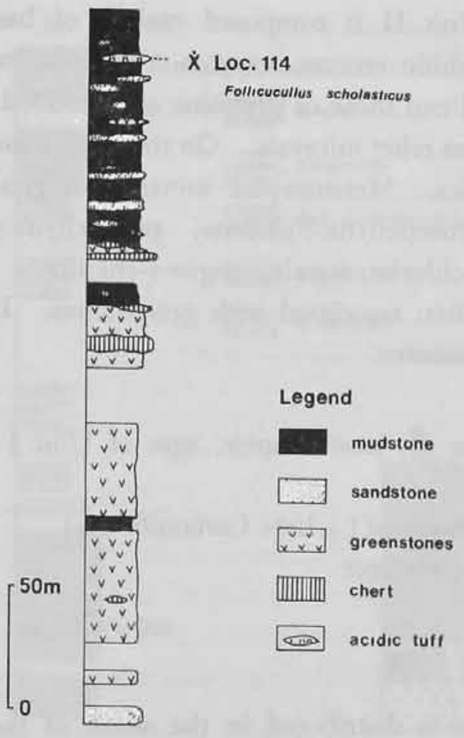


Fig. 15. Columnar sections of the Unit II of the "Shirakidani Group" in Nyujo, Kochi City (Route ⑨ in Fig. 12).

(2) Clastics: Occupying most of the volume of the clastic rocks, ill-sorted black pebbly mudstone contains abundant sheets, blocks and lenses of sandstone in various horizons. In addition, accessory amount of chert and greenstones are also contained as blocks and lenses.

Sandstone is generally massive and occurs in pebbly mudstone as sheet of 1–3 m thick, or as block and lenticular body of 10 cm to several meters in diameter. It is mostly medium- to coarse-grained feldspathic wacke, which usually carries small amount of ill-sorted, subangular pebbles. Sandstone is composed of quartz, plagioclase and rock fragments of basaltic greenstones, felsic to intermediate igneous rocks and pelitic schists. Pebbles comprise sandstone, mudstone and acidic tuff, with minor amount of greenstones of basaltic or gabbroic texture and syenite.

Acidic tuff, found at only one locality, occurs as lenticular body of 1 m in diameter. Dark gray argillaceous acidic tuff contains abundant Permian radiolarians in clay-size matrix.

Clastic rocks of this unit, especially pebbly mudstones, have common characters with the Shingai Formation. As can be observed in Tosayama, however, they are more intensively sheared and folded than the latter, probably reflecting difference in later tectonic experience.

(3) Greenstones: Greenstones show various modes of occurrence, from blocks of 10 cm in diameter to huge sheets of 2 km long and 100 m thick. Larger bodies of greenstones apparently occur as if they were conformable with clastic rocks, but they may be actually allochthonous units enveloped within clastics, as in the case of the Shingai For-

mation. Greenstones of Unit II is composed mainly of basaltic volcaniclastics with minor amount of lavas. Ophitic texture is common in lavas, in which larger pehnocrysts of plagioclase are recognized and those of pyroxene are excluded. Ti-augite and aegirine-augite are rarely recognized as relict minerals. On the other hand, texture of volcanic glass is identified in volcaniclastics. Metamorphic mineral parageneses as far as known are listed below; prehnite+pumpellyite+chlorite, pumpellyite+chlorite, pumpellyite+chlorite+epidote, epidote+chlorite, aegirine-augite+chlorite.

Red bedded chert is often associated with greenstones. It occurs as blocks and/or lenss of less than 10 m in diameter.

E. Age

As will be discussed in the next chapter, ages of Unit I and Unit II are inferred respectively as follows;

Unit I : Early to Middle Permian (+Late Carboniferous)

Unit II: latest Permian? or younger

3. Gonyu Formation

A. Designation

The Gonyu Formation is distributed in the south of the Shingai Formation. It has long been grouped in the Shirakidani Group ("ISHIZAKI, 1960"; SUYARI, 1961). Because of the difference in rock assemblage and the isolated distribution from the proper "Shirakidani Group", however, this formation was tentatively separated from the "Shirakidani Group" by the present author (ISOZAKI, 1985).

B. Stratotype and Distribution

Stratotype (tentative): north of Naka-gonyu, Tosa-yamada Town (Fig. 2).

Distribution: This formation is distributed restrictedly in the eastern part of the study area, i.e. from north of Shingai to Nakagonyu. It crops out as a narrow geologic body extending in E-W direction. Toward the west its tract is thinning off, being covered unconformably by the Cretaceous strata.

C. Stratigraphy and Lithology

This formation is characterized by red bedded chert and greenstones apparently associated with clastics (Fig. 16). In addition, a small amount of dolomite occurs in red bedded cherts. Although details of stratigraphy have not yet been clarified, greenstones, dolomite and chert might have been essentially associated in a stratigraphic succession.

Clear grading recognized within dolomite layers (shown by an arrow in Fig. 16B) indicates that their facings are toward south, in other words, that these rocks are totally up-side-down. Occurrence of conodonts (Fig. 16B) also supports that bedded chert are overturned together with the unconformity surface at Tengudake. Total thickness of the formation is approximately 250 m at the type section.

Bedded cherts are generally brick red to reddish light gray, forming rhythmic alternation of siliceous layer, several centimeters thick, and thin siliceous mudstone film, less than 1 mm thick. Thickness of this chert sequence at Tengudake is apparently up to

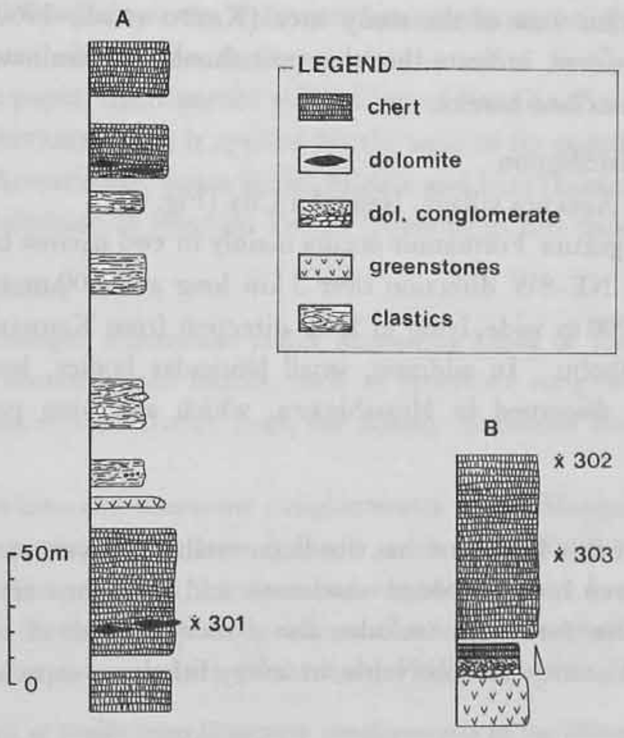


Fig. 16. Columnar sections of the Gonyu Formation in the north of Naka-gonyu, Kami County (A) and at Tengudake, south of Yasuba, Tosa-yamada Town (B).

150 m. Dolomites occur as nodular blocks or thin layers of 10 to 50 cm in thickness, irregularly intercalated in bedded chert. In addition, dolomite conglomerate, with cobble sized clasts and red volcaniclastic matrix, is closely accompanied. The red chert/dolomite association of the same kind and the same age is reported from the Mesozoic Complex (ISOZAKI & MATSUDA, 1980 b), which will be mentioned later.

Greenstones, rather small in amount, consist mainly of massive lava. They occupy an apparent stratigraphic position just below the dolomite conglomerate (Fig. 16B).

Clastic rocks are composed mainly of pebbly mudstone with lenses and blocks of sandstone of various sizes.

D. Age

The age of this formation is probably Permian, but is not certain. See next chapter for details.

4. Agekura Formation

A. Designation

Existence of semi-schistose rocks along the northern margin of the Kurosegawa Tectonic Zone and their geological significance were firstly mentioned by ICHIKAWA *et al.* (1956). The Agekura Formation (ISHIZAKI, 1960) is one of these semi-schistose rocks distributed in Central Kochi Prefecture. This formation name is also applied to another geologic body, which is distributed in the vicinity of Kagamigawa Dam, north of Kochi

City, approximately 5 km west of the study area (KATTO *et al.*, 1960). Lithologic and structural features, however, indicate that this unit should be eliminated from the proper Agekura Formation described herein.

B. Stratotype and Distribution

Stratotype: South of Agekura village, Nangoku City (Fig. 4).

Distribution: The Agekura Formation occurs mainly in two narrow bodies; one in Higashigawa, extending in NE-SW direction over 3 km long and 600 m wide, and the other over 10 km long and 700 m wide, lying in E-W direction from Kameiwa to Tosayama via Naro, Agekura and Shobu. In addition, small lenticular bodies, less than 600 m long and 100 m wide, are discerned in Higashigawa, which are lying parallel south to the former main body.

C. Lithology

As stratigraphy of this formation has not bcen established yet, remarks on individual lithogies are briefly given here. Bedded sandstone and mudstone are chief constituents of this formation. This formation includes also a small amount of comglomerate, chert and greenstones. Schistosity is observable in every lithology, especially conspicuous in pelitic ones.

Light gray mudstone is slightly siliceous. In addition to kink foldings of several centimeters in wave length, micro-corrugations are commonly observable in thin section.

Sandstone is generally massive, or sometimes interbedded with mudstone (each bed in 5–30 cm thickness) with remarkable lamination. It is composed mainly of ill-sorted, medium to fine grains of quartz and plagioclase with minor amount of rock fragments of greenstones and detrital hornblende.

Conglomerate consists of tectonically elongated pebbles of sandstone, mudstone and acidic tuff with matrix of sandstone.

Chert is pale green and well bedded (each bed: less than 5 mm thick) but mudstone film have almost disappeared secondarily.

D. Metamorphism

Any mineral paragenesis indicating particular metamorphic facies has not been recognized yet. In mudstone, abundant muscovite occurs, showing well aligned orientation. Also minor amounts of chlorite and pumpellyite are identified in thin sections.

IV. Fossils from the Paleozoic Complex and their Ages

Limestone and limestone conglomerate in the Paleozoic formations yield various kinds of fossils, such as fusulinids and corals of mostly Permian age (e.g. TORIYAMA, 1942; HASHIMOTO, 1955; ISHIZAKI, 1960; SUYARI, 1961; ISHII & NOGAMI, 1962). Later on, however, Limestone and limestone conglomerate of the Shingai Formation have been revealed to be allochthonous or exotic in origin (ISOZAKI, 1979, 1985). In addition, occurrence of conodonts and radiolarians has been reported in recent years. Thus ages of the formations should be re-assigned along these new lines of evidence.

In this chapter, fossils from the Paleozoic formations are briefly mentioned and ages of these formations are assigned on the basis of informative fossils and their modes of occurrence. In this paper, the tripartite subdivision of Permian Period based on fusulinid biostratigraphy (TORIYAMA, 1967) is applied for the sake of its popularity among Japanese biostratigraphers. Accordingly, terms Early, Middle and Late (Lower, Middle and Upper) will be used for subdivision of Permian Period (System) in this paper.

1. Shingai Formation

Although the Shingai Formation yields numerous kinds of fossils, their occurrence is restricted within allochthonous blocks, such as limestone conglomerate and chert, and no fossil has been recovered directly from the pebbly mudstone forming matrix of these blocks.

From the limestones and limestone conglomerates of the Shingai Formations, various kind of Permian (+partly Carboniferous) fossils, such as fusulinids, smaller foraminifers, corals, bryozoans, algaes, crinoids, bivalves and conodonts, have been obtained. Among them, fusulinids and corals are especially informative in age assignement. Representative species reported by previous workers (TORIYAMA, 1942; KANMERA, 1954; ISHIZAKI, 1960;

Table 2. List of fossils from limestone conglomerates in the Shingai Formation. After ISOZAKI (1985).

Species \ Cgl. Type	II			III					I					
Loc. No.	1	6	9	2	3	4	5	11	7	8	10	12	13	14
Lepidolina multiseptata	X	X												
L. sp.	X	X	X											
Neoschwagerina margaritae				X										
N. craticulifera						X								
N. sp.							X							
Verbeekina sp.	X													
Metadoliolina sp.	X													
Codonofusiella sp.	X													
Parafusulina sp.	X													
Pseudofusulina sp.				X		X								
Zellia sp.				X										
fusulinid gen. et sp. indet.		X			X		X	X	X	X	X			X
Colaniella sp.	X													
Nodosaria sp.	X													
Pachyphloides? sp.	X													
Pachyphoria sp.	X													
Tetrataxis sp.	X													
Palaeotextularia sp.	X													
Waagenophyllum virgalense	X													
Parawentzelella sp.	X													
Iranophyllum sp.											X			
Akagophyllum sp.									X					
Chaetetes sp.									X					
Fistlipora cf. *takauchiensis*											X			
bryozoan gen. et sp. indet.	X		X		X									X
Idiognathodus sp.					X						X			
Streptognathodus sp.					X									
Gnathodus sp.					X	X								
Gondolella sp.					X						X			
conodont gen. et sp. indet.				X	X	X								

ISHII & NOGAMI, 1962; OZAWA, 1975) are as follows;

Lepidolina multiseptata, L. kumaensis, Pseudodoliolina pseudolepida gravitesta, Codonofusiella sp., *Neoschwagerina margaritae, N. craticulifera, Chusenella* sp. *Schwagerina* sp., *Triticites* sp., *Waagenophyllum* sp.

Fossils of other taxa additionally found through the present study are listed in Table 2. Fossil localities are shown in Fig. 6.

In addition to these, abundant conodonts and radiolarians have been recently extracted from siliceous rocks of this formation (ISOZAKI, 1978, 1986; SUYARI *et al.* 1983), as shown in Table 3 and Fig. 6.

A. Fossils from Limestone Conglomerates

Almost all fusulinid genera and species form the limestone conglomerates are of Permian age, ranging from *Pseudoschwagerina* Zone to *Neoschwagerina* Zone. Among them, the youngest is *Lepidolina kumaensis* KANMERA, which is the nominal species of the *L. kumaensis* fauna (KANMERA, 1953). Although precise correlation of this fauna is still in controversy, it is generally treated as earliest Late Permian fauna in Japan (e.g. ISHII *et al.* 1975). *Colaniella*, a genus of smaller foraminifera, was reported from Wuchiapingian and Chansingian of South China and|is regarded to have occurred through Late Permian (WANG, 1966; ISHII *et al.* 1975). *Colaniella* sp. from Loc. 1 resembles *C. minima* WANG. Also *Nodosaria* sp. and *Pachyphloides*? sp. are akin to those reported from Lower Dzulfian of Iran (pers. commun. by Y. OKIMURA).

Rugose coral *Waagenophyllum virgalense* (WAAGEN & WENTZEL) is regarded to occur from Middle Permian, *Neoschwagerina-Yabeina* Zone (MINATO & KATO, 1965). Other genera, *Parawentzellella, Iranophyllum* and *Akagophyllum* were reported from Middle Permian, Lower to Middle Permian and Lower Permian, respectively (op. cit.).

Bryozoan specimen, *Fistulipora* cf. *takauchiensis* SAKAGAMI resembles *F. takauchiensis* described from Takauchi Limestone in the Maizuru Belt (SAKAGAMI, 1961), which is regarded to be of Late Permian age (ISHII *et al.* 1975).

Conodont genera, *Idiognathodus* and *Streptognathodus*, appeared in Morrowan (Early Pennsylvanian) and range up to Wolfcampian (Early Permian) in North America (LANE & STRAKA II, 1972; CLARK & BEHNKEN, 1971). Also in Japan, similar range of occurrence of these genera is reported by KOIKE (1967) and IGO (1981).

B. Age of the Conglomerate

Formerly, some fossils, such as *L. kumaensis* from Loc. 1, were believed to have occurred from matrices of conglomerates and, therefore, were regarded as representative age-indicator of conglomerates. It is revealed, however, that all fossils mentioned above, including *L. kumaensis*, occur from clasts of conglomerates (cf. ISOZAKI, 1985). When a conglomerate contains clasts of various ages and the age of its matrix is unknown, the age of the conglomerate should be regarded as being contemporaneous with or younger than the youngest fossil contained. Based on this principle, the age of each conglomerate is assumed as follows;

Loc. 1: *Lepidolina kumaensis* and *Colaniella* sp. are the youngest. They occur from different clasts, respectively. The age of the conglomerate is supposed to be latest Permian or younger.

Loc. 2: *Neoschwagerina margaritae* DEPRAT is the youngest. The age of the conglomerate is inferred to be latest Middle Permian or younger.

Locs. 3–7, 9, 10: Fossils from these localities are rather scarce in number without coexisting clasts of different ages. Therefore, ages of the conglomerates are roughly inferred to be Early-Middle Permian or younger.

It is noteworthy that species belonging to *Lepidolina* occur restrictedly from limestone conglomerate of Type II.

C. Fossils from Limestones and their Ages

From the limestone blocks contained in pebbly mudstone, several fossils were obtained as follows;

Loc. 35: bivalve gen. et sp. indet.

Loc. 36: *Idiognathodus* sp., *Gondolella* sp.

At present, there is no clue for dating of the limestone at Loc. 35. Age of the limestone at Loc. 36 is supposed to be a cetain time during Pennsylvanian and Early Permian.

D. Fossils from Siliceous Rocks

Reconaissance studies revealed that siliceous rocks contained in the Shingai Formation, namely chert, acidic tuff and siliceous mudstone, yield abundant microfossils, such as radiolarians and conodonts (ISOZAKI, 1978; SUYARI *et al.* 1983). List of conodonts and radiolarians from these siliceous rocks is shown in Table 3, in which sample localities are tentatively grouped according to lithology. Especially for bedded chert at Loc. 29,

Table 3. List of fossils from siliceous rocks in the Shingai Formation. After ISOZAKI (1986).

Species \ Lithology	Sil.Ms.				Acid.Tf.				AT-Ch			29-								Chert							
Loc. No.	19	26	15	22	33	16	18	17	24	34	30	A	B	6	5	4	3	2	1	23	31	21	20	25	27	32	28
Neoalbaillella grypus	X																										
Albaillella levis	X	X	X	X	X																						
A. sp.	X																										
Follicucullus scholasticus			X	X	X	X	X		X	X	X																
F. ventricosus								X		X	X																
F. falx								X																			
F. cf. *monacanthus*											X																
Pseudoalbaillella fusiformis												X															
P. aff. *longicornis*												X															
P. sp. C														X	X												
P. cf. *rhombothoracata*														X	X												
A. sp. D														X	X	X	X										
P. elongata																	X										
P. scalprata																	X										
P. ornata																		X									
P. lomentaria																		X									
P. longicornis																		X	X								
Diplognathodus oertlii															X		?	X		X							
D. augustus													X														
D. sp.									X	X										X	X						
Neostreptognathodus sp.																	X										
Gondolella spp.						X			X	X	X			X	X		X	X	X	X	X	X	X	X	X	X	
Idiognathoides sinuatus																											X
I. corrugatus																											X
Adetognathus lautus																											X
Idiognathodus sp.																											X
G. clarki																											X

columnar section and range chart of microfossils are given in Fig. 17.

(1) Conodonts: Conodonts occurs mainly from bedded chert. In the present study, two assemblages, namely *Idiognathoides sinuatus—I. corrugatus* Assemblage and *Diplognathodus oertlii* Assemblage, have been identified. Components of the former, namely *I. sinuatus* Harris & Hollingsworth, *I. corrugatus* H. & H. and *Adetognathus lautus* (Gunnell), are reported from Morrowan to Atokan (Pennsylvanian) in North America (Lane & Straka II, 1972). The latter assemblage is characterized by *Diplognathodus oertlii* (Kozur), which was originally described as *Gnathodus sicilianus* from Middle Permian Socio Formation in Italy by Bender & Stoppel (1965) and later separated from the latter as new species by Kozur (1975). This assemblage rarely contains *D. augustus* Igo, which was described from Lower Permian limestone in Gujo-Hachiman in the Mino Belt. According to Igo (1981), these two species of *Diplognathodus* co-occur with *Sweetognathus whitei* (Rhodes), which is the well-known index element of Late Wolfcampian in North America (Clark & Behnken, 1971). Judging from above-mentioned facts, age of the *Idiognathoides sinuatus—I. corrugatus* Assemblage and the *D. oertlii* Assemblage are assigned to Late Carboniferous and latest Early to earliest Middle Permian, respectively.

(2) Radiolarians: From siliceous rocks in the Shingai Formation, the following seven radiolarian assemblages were recognized.

Assemblage-1 composed of *Pseudoalbaillella longicornis* Ishiga & Imoto, *P.* cf. *lomentaria* I. & I. and *P.* cf. *ornata* I. & I.

Assemblage-2 composed of *P. scalprata* Holdsworth & Jones, *P. elongata* I. & I. and *Albaillella sinuata* Ishiga.

Assemblage-3 composed mainly of *A. sinuata* with minor amount of *P.* cf. *rhombothoractata* I. & I. and *P.* cf. sp. C Ishiga *et al.*

Assemblage-4 composed of *P. fusiformis* H. & J. and *Albaillella* sp.

Assemblage-5 composed mainly of *Follicucullus scholasticus* Ormiston & Babcock (morphotype II of Ishiga) with *F. ventricosus* O. & B.

Assemblage-6 composed mainly of *F. falx* Caridroit & De Wever with *F. scholasticus.*

Assemblage-7 composed mainly of *A. levis* Ishiga *et al.* with *F. scholasticus* and rarely with *Neoalbaillella grypus* Ishiga *et al.*

Except for the Assemblage-6, all of these assemblages are composed of Permian radiolarian species reported from bedded chert in the Tamba Belt. On the basis of faunal composition, these assemblages are roughly compared with following assemblages described in the Tamba Belt.

Assemblage-1: *P. lomentaria* Assemblage: middle-late Early Permian (Wolfcampian)

Assemblage-2: *P. rhombothoracata* Assemblage: late Early Permian

Assemblage-3: *A. sinuata* Assemblage: latest Early to earliest Middle Permian

Assemblage-4: *P. globosa* Assemblage: middle Middle Permian

Assemblage-5: *F. scholasticus* Assemblage: latest Middle to earliest Late Permian (Guadalupian)

Assemblage-7: *N. ornithoformis* Assemblage: late Late Permian

Probable ages of the assemblages, added after their names, are after ISHIGA *et al.* (1982) and ISHIGA (1986). These ages were assigned on the basis of stratigraphic relationship among these assemblages, co-occurrence with index conodonts and correlation with Sakmarian in Vor-Ural (KOZUR, 1981) and Guadalupian in Texas (ORMISTON & BABCOCK, 1979).

The Assemblage-6 corresponds probably to that recently reported from mudstone in the "Kamigori Zone" by CARIDROIT & DE WEVER (1984). Although direct stratigraphic relation with other assemblage is unkown, its age is probably early Late Permian, as it occurs from the formation characterized by the *L. kumaensis* Assemblage (ISHIGA & MIYAMOTO, 1986).

At Loc. 29, as shown in Fig. 17, successive occurrence of Assemblages-1, -2 and -3, in ascending order, was revealed. Occurrence of the Assemblage-4 from a float block nearby the outcrop may indicate that certain chert with Assemblage-4 was once in succession with the underlying portion with the Assemblages-1, -2 and -3.

E. Ages of Siliceous Rocks

According to the above-mentioned facts, ages of the siliceous rocks listed in Table 3 are estimated as follows;

Loc. 28 (massive chert): Occurrence of *Idiognathoides sinuatus-I. corrugatus* assemblage indicates that this chert is of Pennsylvanian age.

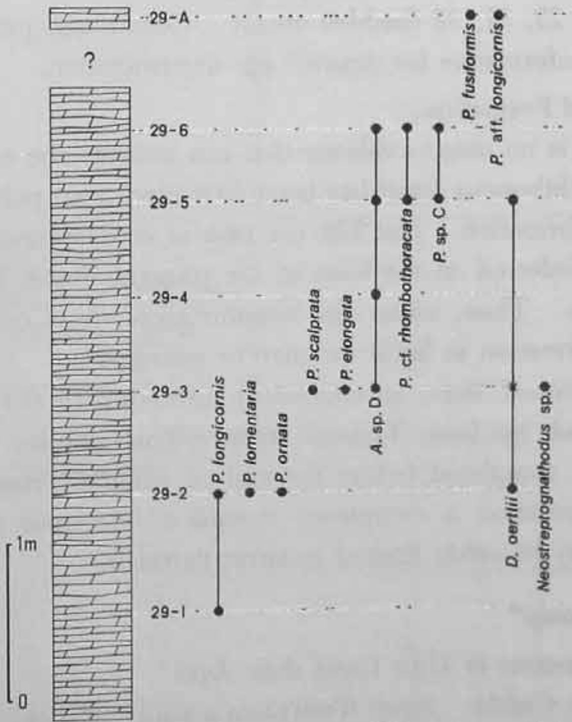


Fig. 17. Stratigraphic distribution of Permian radiolarians and conodonts in a bedded chert at Loc. 29. After ISOZAKI (1986).

Loc. 29 (bedded chert): From this chert block, less than 3 m in thickness, radiolarian Assemblages-1, -2 and -3 were obtained in sequence (samples 29-1--6) in addition to *Diplognathodus oertlii* conodont assemblage. Also *D. augustus* and radiolarian Assemblage-4 were detected in chert samples collected from nearby float blocks (sample 29-A, -B). Chert at Loc. 29 probably ranges from middle Early to middle Middle Permian.

Loc. 23 (bedded chert): Occurrence of *D. oertlii* indicates that this chert belongs to certain time during latest Early and Middle Permian.

Locs. 24, 30, 34 (chert/acidic tuff): Samples from these localities yield the radiolarian Assemblage-5 which presumably indicates latest Middle to earliest Late Permian. Because the assemblage from Loc. 30 solely contains *Follicucullus* cf. *monacanthus*, it is possibly slightly older than the other two. On the other hand, occurrence of *Gondolella serrata* CLARK & ETHINGTON, an index species of Wordian (Lower Guadalupian) in North America, was reported at Loc. 24 (SUYARI *et al.* 1983). Thus this chert probably ranges from middle Middle Permian to earliest Late Permian.

Loc. 16, 18, 33 (bedded acidic tuff): These samples yielding radiolarian Assemblage-5 were regarded to be of latest Middle to earliest Late Permian age.

Loc. 17 (muddy acidic tuff): Sample from this locality is the only one that yields radiolarian Assemblage-6 which represents certain age in latest Middle to Late Permian.

Locs. 15, 19, 22, 26 (siliceous mudstone): The youngest radioalrian assemblage from the Shingai Formation was detected from samples at these localities. These rocks are suggested to be of late Late Permian age.

Locs. 20, 21, 25, 27, 31, 32 (bedded chert): Conodonts, probably of Permian, are obtained but are not informative for detailed age determination.

F. Age of the Shingai Formation

At present, there is no direct evidence that can indicate the exact age of this formation, because no autochthonous fossil has been recovered from pebbly mudstone that occupies matrix of the formation. Just like the case of conglomerate, however, the age of the formation can be inferred on the basis of the youngest fossil, i.e., late Late Permian radiolarian assemblage. Thus, under the circumstances, it is reasonable to assign the age of the Shingai Formation as latest Permian or younger.

As will be mentioned later, an equivalent formation to the Shingai Formation is unconformably covered by Late Triassic strata. This implies that the emplacement of this formation was completed before the end of Middle Triassic at the latest. Because the Shingai Formation is completely devoid of Mesozoic fossils, the age of the Shingai Formation may be safely limited in latest Permian.

2. "Shirakidani Group"

A. Fossils from Limestone of Unit I and their Ages

(1) Fusulinids and Corals: Since TORIYAMA's study in 1947 numerous genera and species of fusulinid and rugose coral had been reported from thick limestones in Tosayama and Shirakidani (e.g. ISHIZAKI, 1960; SUYARI, 1962; HASHIMOTO, 1967; HIRATA, 1975),

which are classified in Unit I of the "Shirakidani Group" in this paper. In addition to these, several fusulinids and corals were newly found out through the present study, as shown in Table 4 and Fig. 12. In terms of fusulinid zones by TORIYAMA (1967), limestone sequence of Unit I comprises *Pseudoschwagerina morikawai* subzone, *Pseudofusulina vulgaris* subzone (*Pseudoschwagerina* Zone, Lower Permian), *Psf. ambigua* subzone and *Neoschwagerina simplex* subzone (*Parafusulina* Zone, Middle Permian). Continuous stratigraphic succession of these zones, however, has not been detected yet, due to later tectonic disturbance.

(2) Conodonts: Several conodonts have been newly detected through present study. List of conodonts from the limestone of Unit I are shown in Table 5. It is worth noting that fusulinids and conodonts never occur together with each other. Also several conodonts were extracted from limestone at Furui in Kahoku Town, approximately 6 km

Table 4. List of fossils from Unit I of the "Shirakidani Group", (1) fusulinids and corals. *: after YAMAGIWA and ISOZAKI (in prep.).

Species / Locality	101	102	103	104	105	106	107	108	109
Pseudoschwagerina sp.					X				
Pseudofusulina vulgaris				X?		X			X
Psf. ambigua		X?	X						
Psf. kraffti			X						
Psf. tschernyschewi			X						
Psf. spp.		X	X	X			X		
Schwagerina sp.			X			X			
Parafusulina sp.								X	
Neoschwagerina cf. *simplex*	X								
N. sp.	X							X	
Verbeekina sp.								X	
Nankinella sp.			X			X			
Schubertella sp.			X						
Neofusulinella sp.			X						
Yokoyamaella (Yokoyamaella) shirakidaniensis n. sp.*			X						
Carinthiaphyllum tosaensis n. sp.*			X						
Parastephyllum (Sakamotozawaella) sp.			X						
Iranophyllum sp.			X						

Table 5. List of fossils from Unit I of the "Shirakidani Group", (2) conodonts.

Species / Loc. No.	F						113	111	112	110				
	1	2	3	4	5	6				1	2	3	4	5
Idiognathodus ellisoni											x			
I. sp.	x									x?	x	x	x	
Idiognathoides sp.				x										
Streptognathodus sp.	x						x							
Diplognathodus sp.							?	x			x	x	x	x
Sweetognathus bogoslovscajae														x
Hindeodus sp. Pa element									x					
Hindeodella sp.	x		x					x		x				x
compound-type		x		x	x	x	x	x	x	x	x	x	x	x

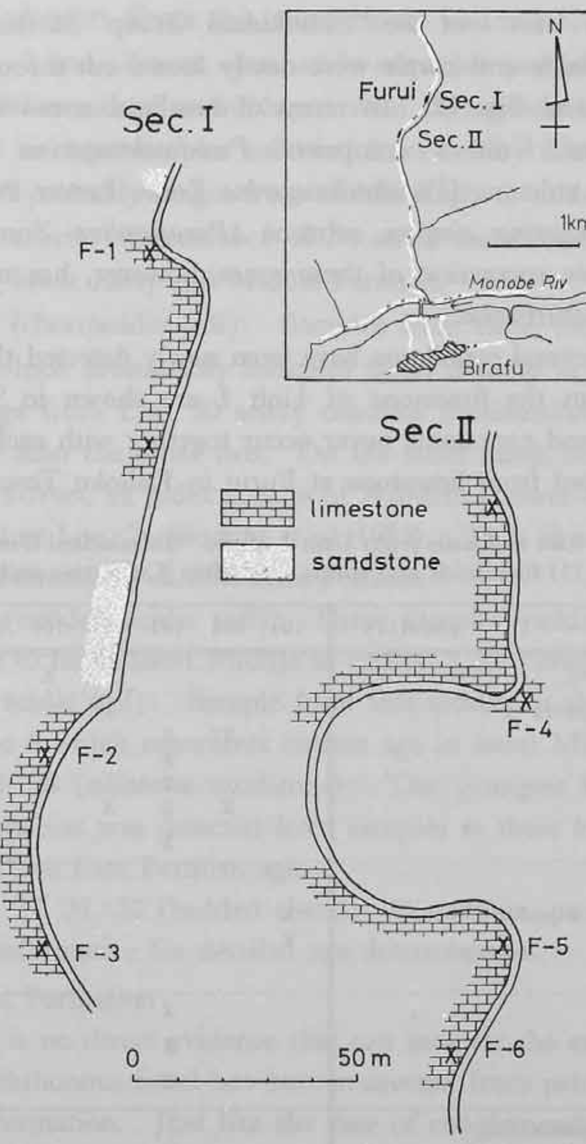


Fig. 18. Route map in Furui area, north of Birafu village, Kami County (Fig. 2), showing sample localities of limestone of Unit I of the "Shirakidani Group".

east of the study area (Fig. 18). This limestone is regarded as the eastern extension of the limestone series of Unit I.

As discussed before, occurrence of genus *Idiognathoides* is restricted in Pennsylvanian (e.g. Morrowan to Atokan in North America; upper Namurian to Westpharian in England) and never from Permian rocks as far as known (LANE & STRAKA II, 1972; HIGGINS & AUSTIN, 1985). On the other hand, *Idiognathodus* and *Streptognathodus* are generally supposed to range from Pennsylvanian to Lower Permian in Europe and North America (LANE & STRAKA II, op. cit.; HIGGINS & AUSTIN, op. cit.; CLARK & BEHNKEN, 1971; KOZUR, 1977). Also in Japan almost similar ranges of occurrence of these genera were ascertained by KOIKE (1967) and IGO (1981). *Idiognathodus ellisoni* CLARK & BEHNKEN was originally described from lower Wolfcampian and is regarded to occur from Virgilian

(Pennsylvanian) to middle Wolfcampian (CLARK *et al.*, 1979). The conodont assemblage from Sample 110-2 corresponds to *I. ellisoni* Assemblage by CLARK & BEHNKEN (1971). *Sweetognathus bogoslovscajae* KOZUR was reported from upper Artinskian in Ural (KOZUR & MOSTLER, 1976). The assemblage from Sample 110-5 can be referred to *Neogondolella bisselli-Sweetognathus whitei* Assemblage by CLARK & BEHNKEN (op. cit.).

On the basis of the data mentioned-above, ages of the limestones at Locs. 110 and 113, which are free from fusulinids, are of Pennsylvanian to early Early Permian and early to late Early Permian, respectively.

It is noteworthy that limestone at Loc. 110 (Fig. 19) yields equivalents of *I. ellisoni* Assemblage and *N. bisselli-S. whitei* Assemblage in succession. Except for this case, there is no example of successive occurrence of two or more assemblages in row within a single outcrop.

(3) Age of the Unit I: On the basis of the aforementioned fossils, it can be concluded that most of the limestones of Unit I are of Early to Middle Permian age and probably range down into the Pennsylvanian in part. Several Carboniferous limestones with quite similar lithofacies were reported from neighbouring areas (SUYARI, 1961; KATTO & KAWASAWA, 1958) as different geologic units. They probably correspond to Carboniferous counterparts of the limestone sequence of Unit I. Age of the greenstones that underlies the limestone is not certain but is probably Carboniferous in most part.

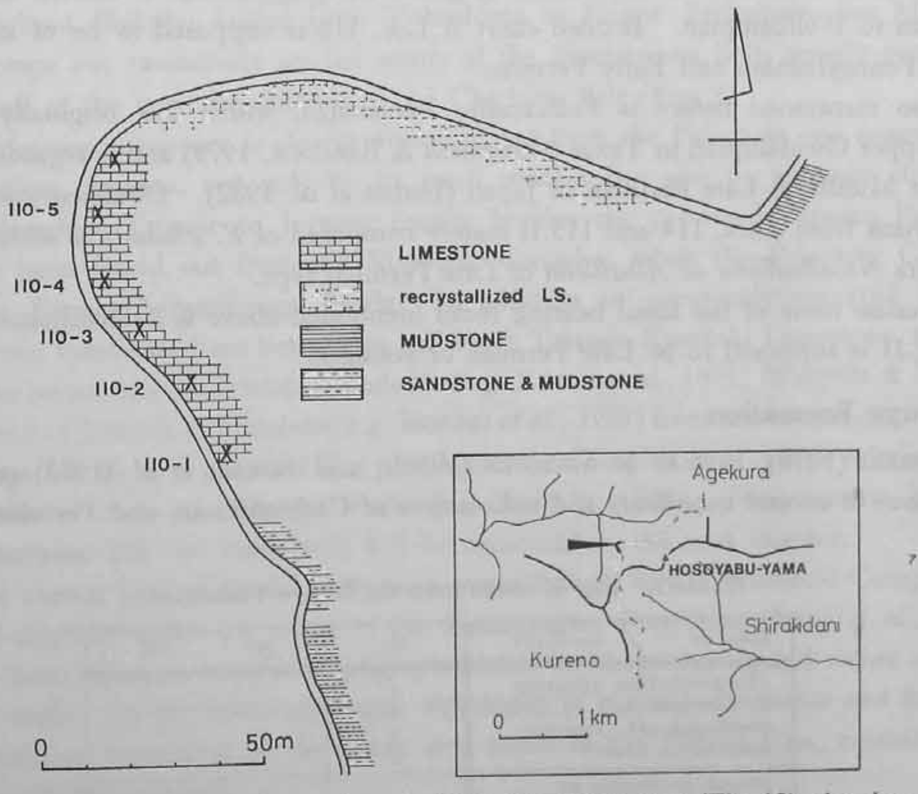


Fig. 19. Route map in the northwest of Mt. Hosoyabu-yama (Fig. 12), showing sample localities (Locs. 110-1—5) of limestone of Unit I of the "Shirakidani Group".

B. Fossils from Siliceous Rocks of Unit II and their Ages

There had long been no report on fossil from the rocks belonging to Unit II. Recently, however, ISOZAKI (1980) and SUYARI *et al.* (1983) found some Permo-Carboniferous conodonts and Permian radiolarians from cherts, respectively. In addition to these, some Permian radiolarians were obtained from muddy acidic tuff through this study. Conodonts and radiolarians from Unit II are listed in Table 6. Fossil localities are shown in Fig. 12.

Table 6. List of fossils from Unit II of the "Shirakidani Group".

Species / Locality	116	114	115
Streptognathodus sp.	x		
Gondolella spp.	x	x	
Follicucullus scholasticus morphotype II		x	
F. aff. *scholasticus*			x
F. sp. B			x

Bedded chert from Locs. 115 and 116 are intimately associated with greenstones. On the contrary, muddy acidic tuff at Loc. 114 is a block of 1 m in diameter, enveloped by surrounding pebbly mudstone.

As mentioned before, occurrence of genus *Streptognathodus* is known from Pennsylvanian to Wolfcampian. Bedded chert at Loc. 116 is supposed to be of certain time during Pennsylvanian and Early Permian.

Also mentioned before is *Follicucullus scholasticus*, which was originally described from Upper Guadalupian in Texas (ORMISTON & BABCOCK, 1979) and is regarded to occur in latest Middle to Late Permian in Japan (ISHIGA *et al.* 1982). Obtained assemblage of radioalrians from Locs. 114 and 115 is mainly composed of *F. scholasticus* without species of genera *Neoalbaillella* or *Albaillella* of Late Permian type.

Because none of the fossil bearing rocks mentioned-above is autochthonous, the age of Unit II is supposed to be Late Permian or younger.

3. Gonyu Formation

ISOZAKI (1978), ISOZAKI & MATSUDA (1980b) and SUYARI *et al.* (1983) reported on occurrence of several conodonts and radiolarians of Carboniferous and Permian age from cherts.

Table 7. List of fossils from the Gonyu Formation.

Species / Locality	301	303	302
Idiognathoides sinuatus	x		
I. corrugatus	x		
Gnathodus aff. *kanumai*	x		
Gondolella clarki	x		
Streptognathodus sp.		x	
Diplognathodus oertlii			x
Gondolella spp.	x	x	x
Hindeodus sp. Pa element		x	

Dolomite at Loc. 301 yields abundant conodonts of Morrown-Atokan age, such as *Idiognathoides corrugatus, I. sinuatus* and so forth (Table 7). Such conodont assemblage have been reported from similar dolomites contained in the Mesozoic Complex in Ehime, Kochi and Tokushima Prefectures (ISOZAKI & MATSUDA, 1980b; ISOZAKI, 1981; ISOZAKI *et al.*, 1981).

Bedded chert at Tengudake (Locs. 302, 303) yields some conodonts, such as *Diplognathous oertlii* which indicates late Early to early Middle Permian age. Also conodont and radiolarian specimens, such as *Streptognathodus* sp. and *Follicucullus* sp., were detected from different horizons respectively at the same locality. Age of the chert sequence at Tengudake, therefore, possibly ranges from Pennsylvanian to latest Middle or Late Permian.

The age of the Gonyu Formation is still not certain at present, but it is evident that the formation is completely free from Mesozoic fossils. Thus this formation is regarded to be emplaced probably during Late Permian time.

V. Mesozoic Complex in the Northern Subbelt of the Chichibu Belt in Central and Eastern Shikoku

1. General Accounts

Throughout Shikoku Island from Tokushima to Ehime Prefecture, the Mesozoic Complex crops out extensively on the south of the Sambagawa Belt, mostly occupying northern half of the northern subbelt of the Chichibu Belt (Fig. 2).

The Mesozoic Complex is clearly discriminated from the Paleozoic one described in the proceeding chapters, not only by its fossil content but also by geologic structure. Namely, abundant Triassic to Jurassic fossils, besides the previously known Paleozoic ones, have been found out from the Mesozoic Complex, while the Paleozoic Complex yields only Permo-Carboniferous fossils. In addition to previously reported Permo-Carboniferous fusulinids from limestones and Early Triassic Kurotaki Limestone, recently revealed are occurrence of Triassic conodonts (e.g. KOIKE *et al.*, 1971; MAEJIMA & MATSUDA, 1977) and of Jurassic radiolarians (e.g. ISOZAKI *et al.*, 1981) from siliceous rocks. These new findings led us to a proposal that the Mesozoic Complex is a chaotic admixture of various kinds of rocks of different origin (e.g. ISOZAKI, 1981). Difference in geologic structure between the two complexes will be presented in the next chapter.

In the central part of Kochi Prefecture, rocks belong to the Mesozoic Complex are treated all together under the name of the Kamiyakawa Formation (ISHII *et al.*, 1957). There has been given no detailed stratigraphic basis for these chaotic and rather strongly tectonized rocks. In the following pages, lithologies of major components and fossils of the Kamiyakawa Formation in the study area south of the Nebiki Pass, central Kochi Prefecture, will be described.

Besides a summary of the Kamiyakawa Formation, added for supplement are short remarks on the Kenzan Group (HIRAYAMA *et al.*, 1956) in the west of Mt. Kumoso, Naka and Myozai Counties, Tokushima Prefecture (Figs. 1, 21). As full documentation of the Mesozoic Complex is not the main purpose of the present paper, it will be briefly mentioned just for comparison with the Paleozoic Complex.

2. Kamiyakawa Formation

The Kamiyakawa Formation is distributed in the northern half of the northern subbelt of the Chichibu Belt in central Kochi Prefecture. The type locality of the formation was set up in Kamiyakawa, Agawa County by Ishii *et al.* (1957). Suyari (1961) applied this name extensively for all of the weakly metamorphosed rocks distributed on the north of the "Shirakidani Group" in Kochi Prefecture and regarded these rocks to be of Permian age as a whole, on the basis of occurrence of fusulinids from limestone blocks. In late 1970s, however, Triassic conodonts were found out from siliceous rocks (Isozaki, 1978; Suyari *et al.*, 1979), and in turn in early 1980s, Jurassic radiolarians were extracted from siliceous and clastic rocks (Suyari *et al.,* 1983).

The Kamiyakawa Formation in the study area, south of Nebiki Pass (Fig. 20), shows monotonous homoclinal structure, dipping north at angles of 35–80°. Apparent total thickness of these rocks exceeds 2000 m.

A. Lithology

It is composed mainly of thick greenstones, bedded cherts and clastic rocks with minor amounts of limestone and dolomite.

Greenstones generally occur as huge geologic bodies which are about 5 km long and 400 m thick in average. They are composed of basaltic lavas and volcaniclastics. Lavas are mostly massive and in some cases pillow structure can be observed. Some of them are alkalic and possess megacrysts (5 mm to 1 cm) of olivine, Ti-augite, kaersutite and/or Ti-biotite. Following parageneses of metamorphic minerals are known; prehnite + pumpellyite + chlorite, prehnite + chlorite, riebeckite + stilpnomelane + chlorite + calcite.

Cherts occur in various sizes from large bodies of about 2 km length and 200 m thickness to small blocks of about 30 cm in diameter. They can be classified into two types, namely Permian chert and Triassic one. The former is usually red and commonly associated with greenstones. On the other hand, the latter is dark gray and accompanies siliceous mudstone in many cases. Both of them are well bedded in 2–5 cm thickness intercalated with very thin films of mudstone. Although they contain abundant microfossils such as radiolarians and conodonts, most of them are ill-preserved.

Clastic rocks are composed mainly of mudstone and sandstone. Mudstones are generally massive and very rarely interbedded with sandstone. Mudstones of the former type are often chaotic, containing blocks of various sizes and lithologies such as sandstone, chert, limestone and greenstones. As matrices of these blocks, the mudstones are pebbly with ill-sorted grains and clasts.

Sandstones are mostly massive without conspicuous sedimentary structures. In rare cases, lamination can be observed clearly due to alignment of pebbles contained. Most of these sandstones are medium-grained and are generally classified in feldspathic wacke.

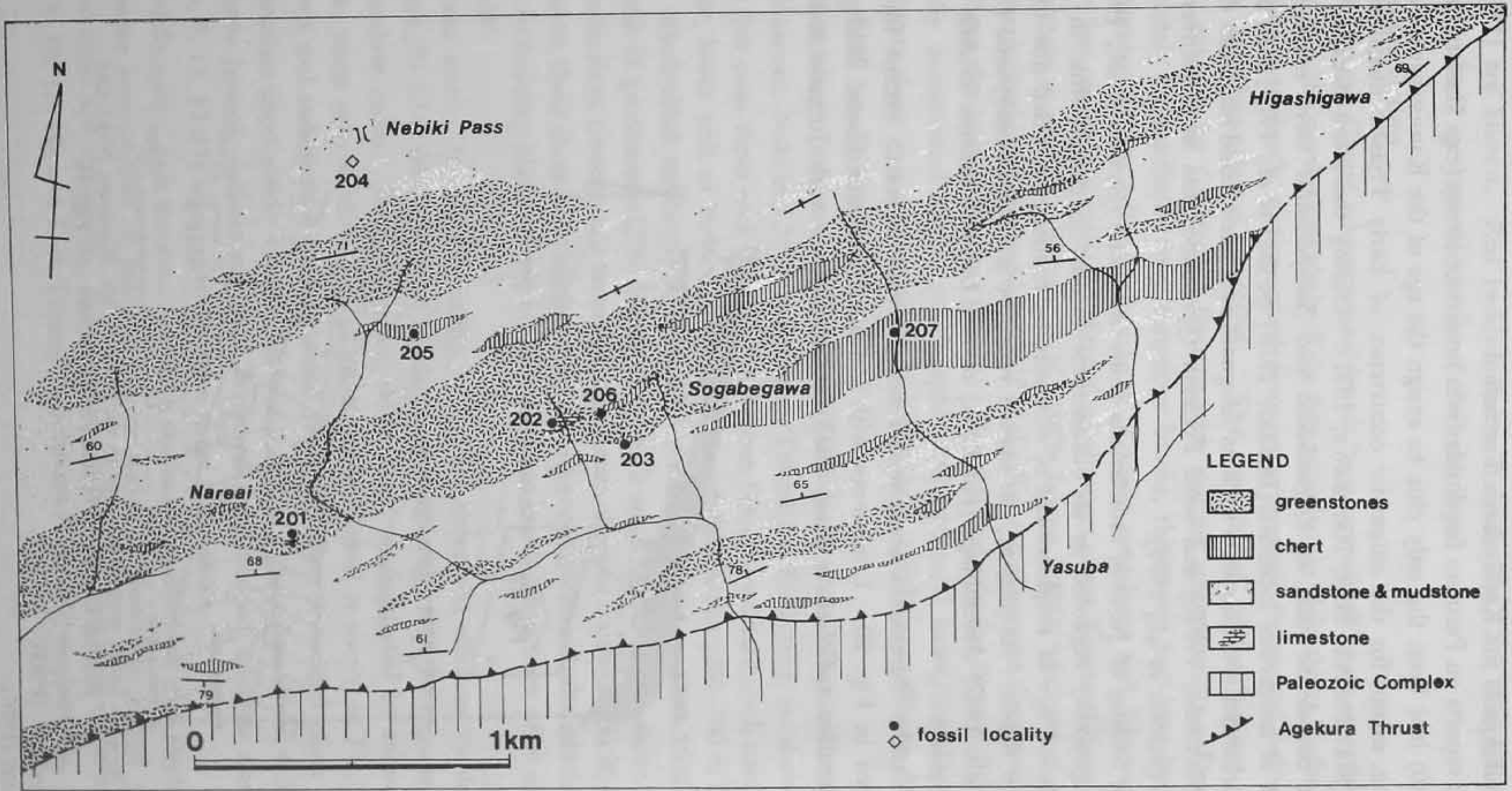


Fig. 20. Lithologic map of the Kamiyakawa Formation in the north of the Yasuba-Shirakidani area, central Kochi Prefecture (cf. Fig. 3).

B. Fossils and Age of the Kamiyakawa Formation

Sporadic reports on Permian fusulinids from limestone lenses (e.g. Hashimoto, 1955; Ishizaki, 1960) had been the only clue to assign the age of the Kamiyakawa Formation for a long time, except for the enigmatic occurrence of Early Triassic megafossil fauna in Kurotaki (Matsushita, 1926; Nakazawa, 1971). During the latest decade, Early to Late Triassic conodonts such as *Epigondolella* and *Neospathodus* were extracted from bedded chert at numerous localities (Isozaki, 1978; Suyari *et al.*, 1979; Koike, 1979). Also some Carboniferous conodonts such as *Idiognathoides* were found out from dolomites (Isozaki & Matsuda, 1980b) and some Permian type conodonts were recovered from bedded chert (Suyari *et al.*, 1979).

After the finding of Jurassic radiolarians from mudstone (Suyari *et al.*, 1983), this formation is generally regarded as an olistostrome formed in certain time in Jurassic. However, detailed age of emplacement of olistostrome remains unsettled due to lack in refined data on fossils. At present, the known youngest is *Hsuum hisuikyoense* (=*H.* sp. B of Yao *et al.*, 1982) Assemblage (radiolaria) of late Early to earliest Middle Jurassic age from mudstone.

In the Yasuba-Shirakidani area, occurrence of fossil is scarce except for several localities shown in Fig. 20. Limestones with Permian fusulinids (Locs. 201*, 202**), chert with Permian radiolarians (Loc. 203*) and mudstone with Jurassic radiolarians

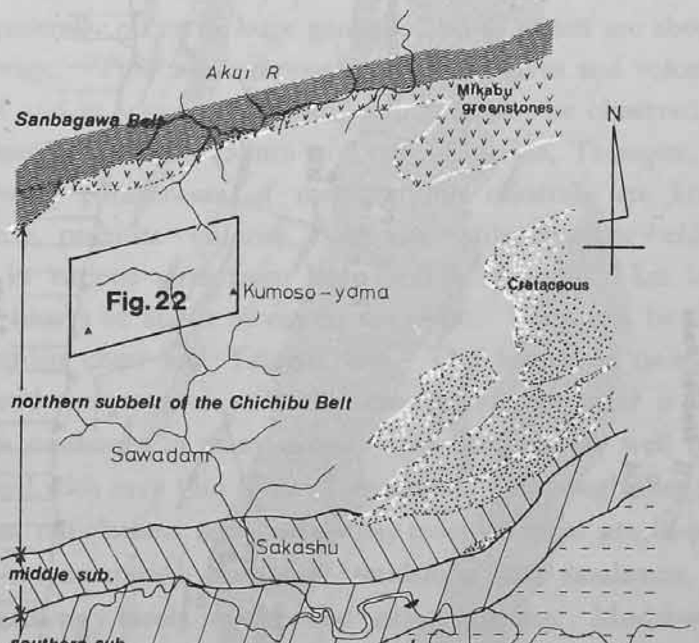


Fig. 21. Index map of the area in the west of Mt. Kumoso, Naka and Myozai Counties, Tokushima Prefecture (cf. Fig. 1).

* After Suyari *et al.* (1983).
** After Ishizaki (1960).

(Loc. 207*) are known. Red bedded cherts at Locs. 204, 205, 206 yield ill-preserved conodonts, which are regarded to be of Permian type.

3. Kenzan Group

The Kenzan Group, characterized by its "eugeosynclinal" rock assemblage, is widely distributed in the northern subbelt of the Chichibu Belt in Tokushima Prefecture (Fig. 21). This group was firstly distinguished from other geologic units and defined as Permian sequence by HIRAYAMA *et al.* (1956). The eastern half of the Kenzan Group is extensively covered by Cretaceous System with distinct unconformity. Due to poor age control solely by fusulinids from limestone blocks, this group had long been believed to be of Permian in age. Recent finding of Triassic conodonts and Jurassic radiolarians, however, has completely emended chronological aspect of the Kenzan Group (e.g. ISOZAKI, 1981; ISOZAKI *et al.*, 1981; SUYARI *et al.*, 1982; ISHIDA, 1985). SUYARI *et al.* (1982) proposed discrimination of the northern half of the Kenzan Group in the name of Kamiyama Group from the proper Kenzan Group. However, criteria for the subdivision have not been fully documented yet on stratigraphic and structural bases, therefore, the present author treats them as a whole under the same name, the Kenzan Group in this paper.

A. Apparent Stratigraphy and Lithology

The lithologic map and apparent geologic column of the Kenzan Group in the west of Mt. Kumoso, Naka and Myozai Counties, Tokushima Prefecture, are shown in Figs. 22, 23. In this area, three rock units of the Kenzan Group are distributed, namely in ascending order, lower unit of bedded chert and siliceous mudstone (200–300 m thick), middle unit of interbedded mudstone and sandstone with chert lenses (800–1600 m thick) and upper unit of greenstones (200–500 m thick) with small blocks of limestone and dolomite. These units form monotonous homoclinal structure, dipping southward in 30–60°. Actually, however, these three units are bounded by rather conspicuous faults which strike slightly oblique to bedding planes of the strata. In other words, they form piled nappe structure as a whole.

Lower unit: It consists mainly of bedded chert and siliceous mudstone. Many thin slices (20–50 m thick) of these lithologies, varing in age from Permian to Jurassic, pile up in random order. In many cases, these slices are separated by minor faults. For example, route map in the north of the Kumoso Tunnel is shown in Fig. 24. Permian conodonts and radiolarians were obtained from one slice of bedded chert (Locs. 6a, b), while another chert yields Triassic conodonts and/or radiolarians (Locs. 4, 5a, 8). Moreover, Early Jurassic radiolarians were extracted from bedded siliceous mudstone (Locs. 1–3, 5b, 7, 11, 13–17) intervened between these chert slices.

Middle unit: It is composed of black mudstone interbedded with sandstone. There occur some intercalation of black mudstone which is chaotically mixed with ill-sorted blocks of chert and sandstone. Several blocks of bedded chert yielded Permian conodonts (Locs. 9, 10, 12, 19) and Late Triassic radiolarians (Loc. 18), respectively.

* After SUYARI *et al.* (1983).

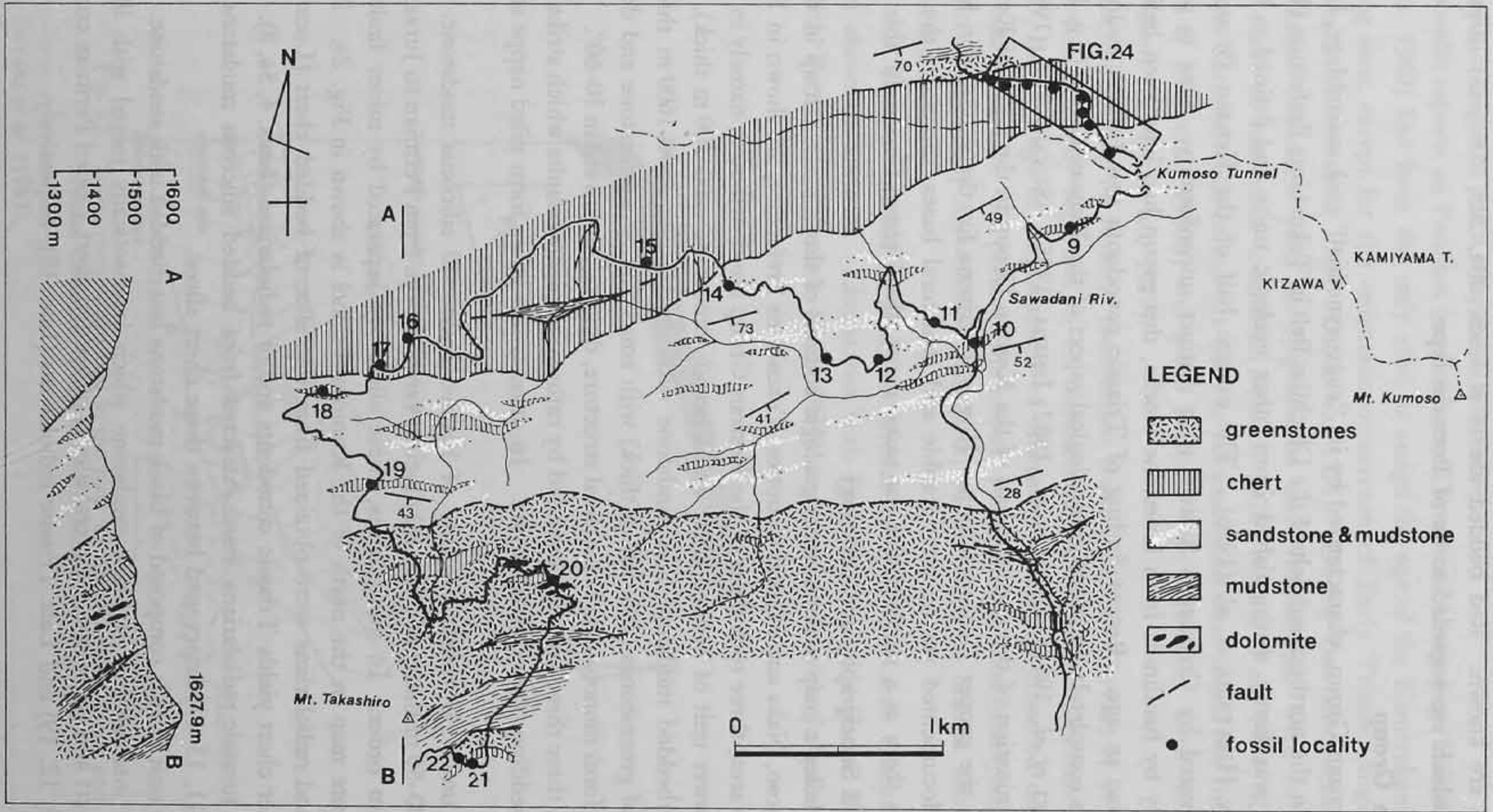


Fig. 22. Lithologic map of the Kenzan Group in the west of Mt. Kumoso (Fig. 21).

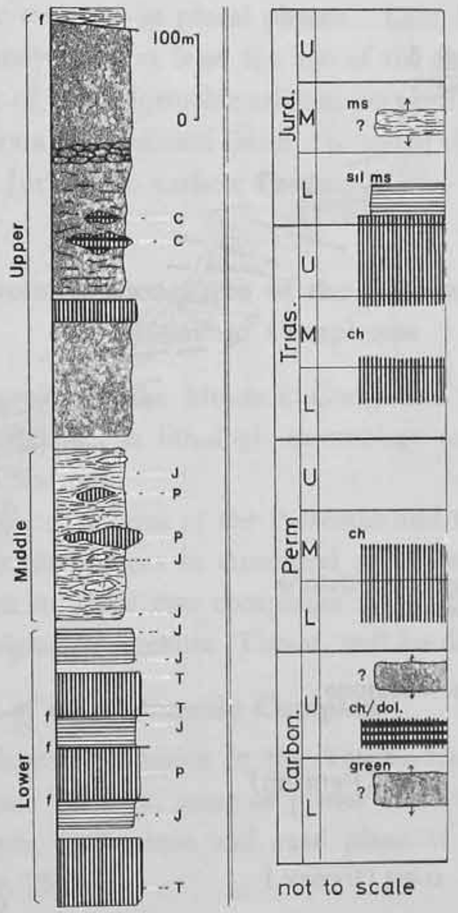


Fig. 23. Schematic geologic column of the Kenzan Group. A. apparent stratigraphy, B. restored order of deposition. Letter f indicates minor fault development. Abbreviations C, P, T and J represent occurrences of Carboniferous, Permian, Triassic and Jurassic fossils, respectively.

Upper unit: It consists of thick greenstones, namely basaltic lavas, diabase and volcaniclastics of the same kind. In addition, mudstone and sandstone are occasionally intercalated and they have the same characters with those of the middle unit. Volcaniclastics contain blocks of limestone and those of dolomite closely associated with red bedded chert. Late Carboniferous conodonts were found in dolomite blocks (Locs. 20, 21, 22), and in turn, Permian fusulinids were recovered from limestone block which occurs side by side with those of the Carboniferous dolomite.

B. Age of the Kenzan Group

As mentioned above, the Kenzan Group contains rocks of various ages ranging from Late Carboniferous to Early Jurassic. In the neighbouring area, Ishida (1985) recently reported almost the same radiolarian assemblages. As far as known up to now, *Hsuum hisuikyoense* Assemblage from mudstone indicates the youngest age, late Early to earliest Middle Jurassic. Judging from their mode of occurrence, these fossil-bearing rocks are mostly allochthonous bodies, secondarily contained in the surrounding clastic rocks.

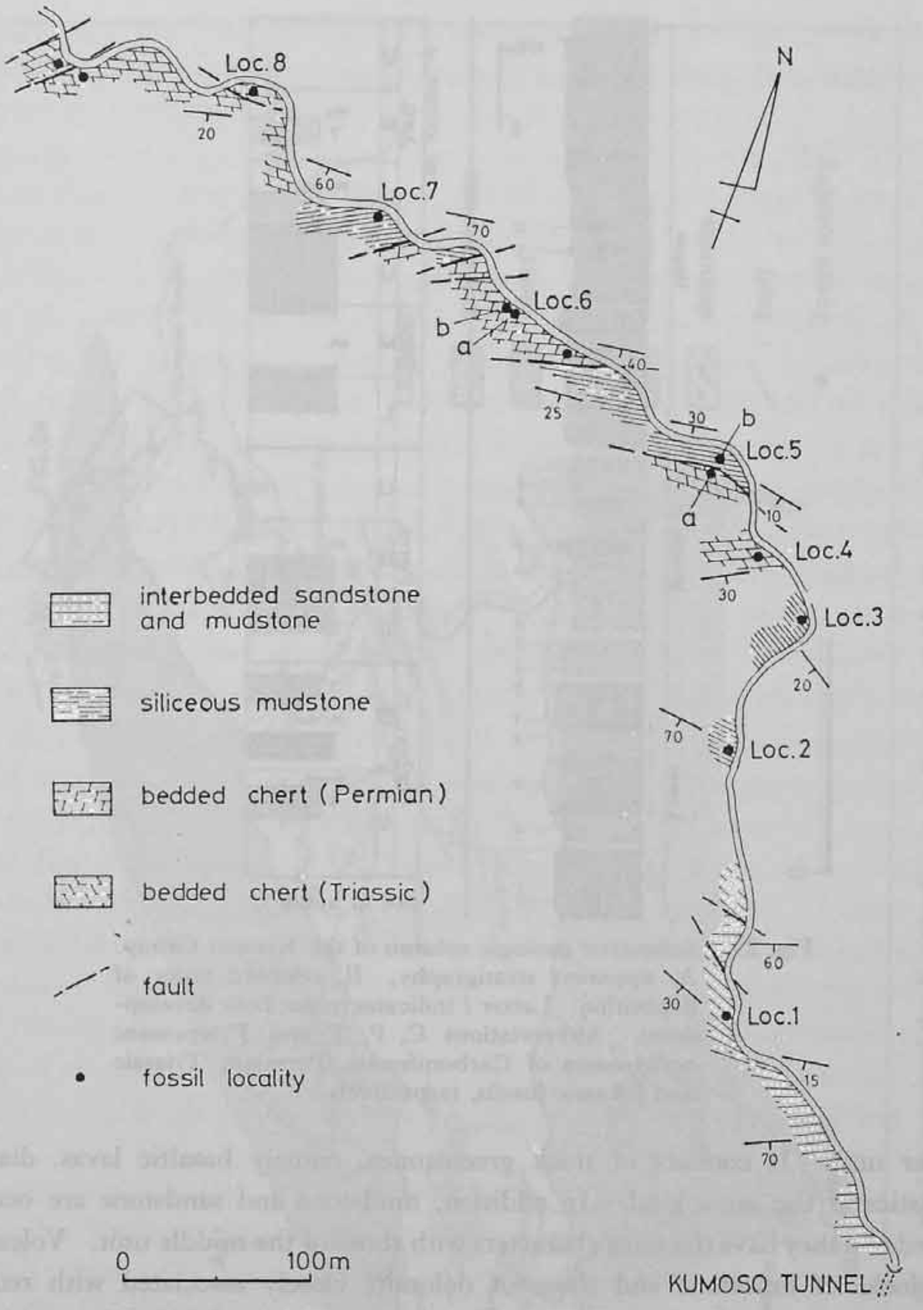


Fig. 24. Route-map in the north of the Kumoso Tunnel (cf. Fig. 22). After Isozaki (1981).

Precise age of the clastics forming matrices of these chaotic rocks has not been determined yet, owing to poor and scarce preservation of fossils. Certain time in later half of Jurassic, however, may be a promising candidate for the age of emplacement of these chaotic rocks.

In the eastern extension of the Kenzan Group in the Kii Peninsula, *Lithocampe nudata* Assemblage (radiolaria) of late Middle Jurassic age was obtained from mudstone (Kurimoto, 1986). Moreover, latest Jurassic radiolarian assemblage was detected from the Mikabu Greenstones (Iwasaki *et al.*, 1984), which are distributed on the north of the Kenzan Group.

It is still not certain whether the Mesozoic Complex in the northern subbelt was formed in a single tectonic event or in plural phases. Late Middle to latest Jurassic age of clastic rocks, however, may mark at least the age of the final stage in emplacement of these rocks. On the basis of unconformable relation between the Mesozoic Complex and the overlying Cretaceous strata of Sotoizumi Basin, the age of the final emplace ment can be further restricted in latest Jurassic to earliest Cretaceous.

VI. Geologic Structures of the Paleozoic and the Mesozoic Complexes

Above-described Paleozoic and the Mesozoic Complexes are well distinguished from each other, not only by difference in lithologic assemblage and age, but also by distinct contrast in their structural features.

In this chapter, geologic structures of the Paleozoic and the Mesozoic complexes are described and their mutual differences in structural styles are mentioned. In addition, present spatial arrangement of these two complexes and nature of the boundary fault between them, newly designated Agekura Thrust, will be discussed.

1. Geologic Structures of the Paleozoic Complex

The rocks of the Paleozoic Complex in the Yasuba-Shirakidani area are generally characterized by steep dips. Namely, most of planer structures of the Paleozoic Complex, such as bedding plane, fault plane and axial plane of fold, dip 40–80° and often stand almost vertically (Fig. 25).

A. Shingai Formation

The Shingai Formation forms a pair of syncline and anticline, whose axes strike in E-W direction with subhorizontal plunge. Strike of the rocks generally parallels the fold axes; they dip mostly 40–80° northward or southward. Especially on the northern limb of the anticline, most of the rocks steeply dip northward, therefore, they are structurally almost concordant with the tectonic slices of the "Shirakidani Group".

In addition to the major folds, there develop some minor folds of 10 m or less in wavelength. Their axes strike mostly in parallel with those of the major ones.

Ikuma (1980) and Ikuma *et al.* (1981) reported that pre-Cretaceous rocks have undergone post-Early Cretaceous deformation in the form of upright folding together with the overlying Cretaceous strata. However, it is generally hard to trace fold axes of the Cretaceous rocks (cf. Fig. 2) further into the Shingai Formation because of cóncealed development of small-scale isoclinal folds within the Shingai Formation. Distinction of deformation phases, e.g. that between pre-Cretaceous one and post-Cretaceous one, looks difficult owing to olistostromal nature of the rocks and scarcity in geopetal fabrics. Post-Createaceous lateral shortening in N-S direction is supposed to have been expressed within the Shingai Formation possibly in the form of minor folding and faults.

B. "Shirakidani Group"

The two units of this group occur as tectonically separated, thin geologic bodies,

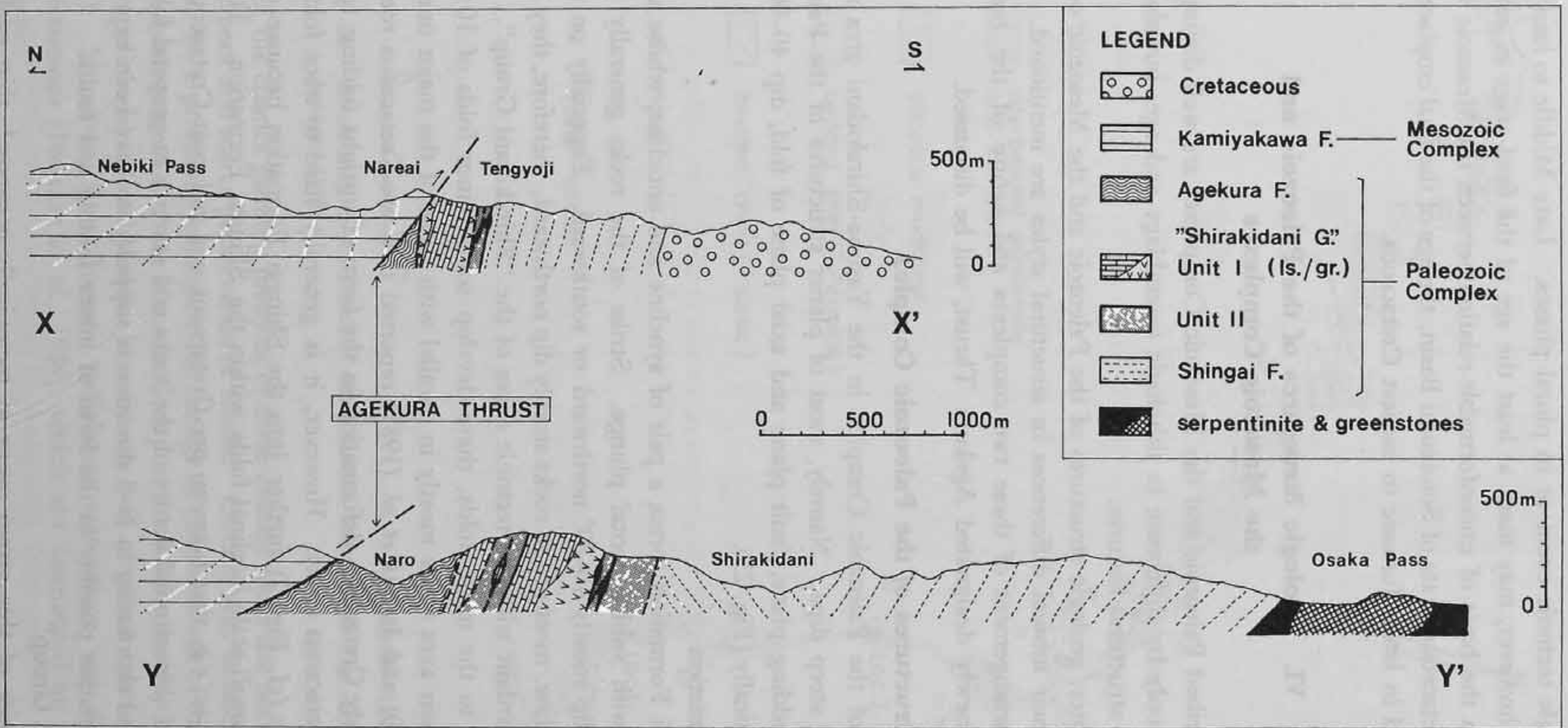


Fig. 25. Geologic profiles of the Yasuba-Shirakidani area, central Kochi Prefecture. See Fig. 3 for their locations.

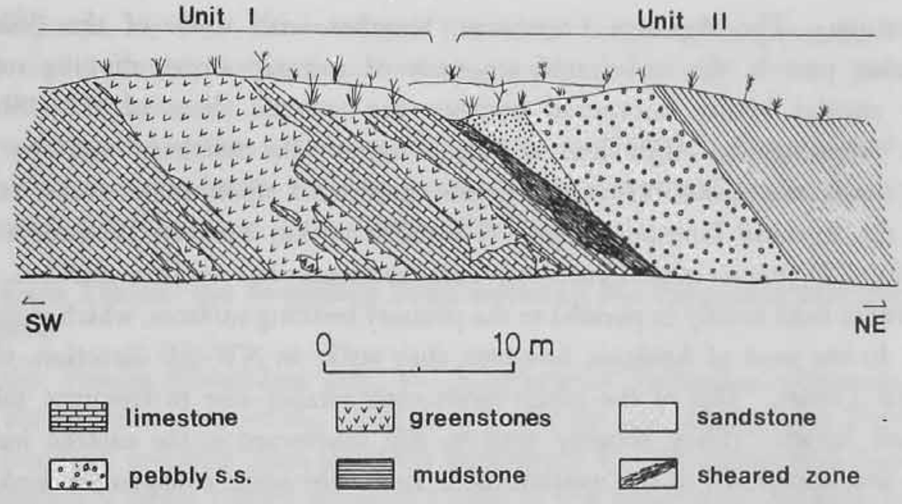


Fig. 26. Sketch of an outcrop showing contact between Unit I and Unit II of the "Shirakidani Group" at the Quarry in Kotaki, Shirakidani.

which are called tectonic slices in this paper. These tectonic slices pile up one after another to build the north-dipping imbricated framework as a whole. General geometry of individual slice is elongated lenticular body of 1–4 km in length and 50–500 m in width. The slices are separated from each other by north-dipping high-angle (50–80°) faults. Fault products such as gouge are generaly small in amount as exemplified in Fig. 26. Along these faults, small serpentinite bodies of 1–50 m in width are intervened between the slices.

Within individual tectonic slices, rocks strike mostly parallel-subparallel to extension of slices and dip steeply, mostly northward. Compared with those of the Shingai Formation, mudstones of Unit II are rather strongly sheared and sporadically cleft.

In addition to primary olistostromal complexity, secondary tectonic disturbance makes it difficult to recognize detailed stratigraphic succession and extent of individual tectonic slices. Hence these tectonic slices shown in the geologic map may be further divided into much thinner and/or shorter slices.

C. Gonyu Formation

The rocks of the Gonyu Formation generally strike in E-W direction and dip apparently northward at 45–80°, forming homoclinal structure as a whole.

This formation is separated from the Shingai Formation, on the north, by a high-angle fault, while on the south, it is unconformably overlain by the Cretaceous Ryoseki Group, which is presently overturned in the northern limb of a syncline to dip northward. Accordingly, rocks of the Gonyu Formation, bounded from the Lower Cretaceous rocks by subparallel unconformity plane, should have been overturned together with the latter. Facings detected in dolomite and biostratigraphic relation within chert (Fig. 16B) are in concert with this speculation.

D. Agekura Formation

Schistose rocks of the Agekura Formation crop out just between the Kamiyakawa Formation on the north, and the "Shirakidani Group" on the south, showing linear lateral extension. The Agekura Formation, together with units of the "Shirakidani Group", takes part in the imbricated structure of tectonic slices, dipping northward. Except for smaller bodies intervened between the tectonic slices of the "Shirakidani Group" in Higashigawa, major bodies usually occupy the northernmost row of these slices. As the Kamiyakawa Formation thrusts southward upon these rocks, completely concealing the Agekura Formation below it for about 3 km between Wakamiya Spa and Kameiwa (Fig. 12), precise inner structure of these sequences has not been clarified. Schistosity of the rocks runs mostly in parallel to the primary bedding surfaces, which strike in E-W direction. In the west of Agekura, however, they strike in NW-SE direction, oblique to the Agekura Thrust. Dip of the rocks varies considerably due to frequent foldings of various wave length. They roughly tend to dip southward in the eastern half of the study area and northward in the western half. In smaller scale, conspicuous kink foldings are frequently observed.

2. Geologic Structures of the Mesozoic Complex

In good contrast with the Paleozoic Complex, the Mesozoic Complex is characterized by the geologic structures of gentle dips. Although later tectonic processes have secondarily made these rocks dip steeply northward or southward, they are supposed to have been primarily inclined gently in most areas.

A. Kamiyakawa Formation

The Kamiyakawa Formation in the Yasuba-Shirakidani area, central Kochi Prefecture, forms a large-scale open synform with upright axial plane. In this area on the southern limb of the synform, rocks generally strike in E-W direction and dip northward. On the other hand, in the northern 2/3 of its distribution, rocks of the Kamiyakawa Formation monotonously dips southward, as can be observed around the Ananai Water Reservoir on the north of the Yasuba-Shirakidani area. These rocks actually dip at rather steep angles, 40–75°, at many outcrops, however, the envelop of the minor-scale foldings is almost horizontal.

In the southernmost part of the formation, strike and dip of the rocks vary considerably owing to post-Cretaceous tectonic disturbance probably by the Agekura Thrust.

Also in the western part of Kochi Prefecture, primary horizontal structure of the rocks with similar open synform was recognized in the equivalents of the Kamiyakawa Formation (Kimura & Horikoshi, 1956; Tsukuda *et al.*, 1981). Furthermore extensive development of piled nappe structure has been recently revealed (e.g. Tsukuda *et al.*, 1981; Hada & Ichikawa, 1982).

B. Kenzan Group

The Kenzan Group in Tokushima Prefecture is also essentially characterized by gently dipping, rather horizontal structures (cf. Fig. 22). For example, these rocks in the west of Mt. Kumoso, Kizawa village, show low-angled (30–45°), piled nappe structure with general strike in E-W direction and southward dip.

As in the case of the Kamiyakawa Formation, actually measured dip of the rocks are not so gentle, however, the envelop of the minor-scale foldings possesses fundamentally gentle dips. Steeply inclined present appearance is probably due to post-Cretaceous tectonic modification.

Concerning the eastern extension of the Agekura Thrust in Tokushima Prefecture, it is noteworthy that northward dipping structure can be observed in the southernmost part of this group (cf. KANMERA, 1969; ISHIDA, 1985).

3. Agekura Thrust: the Boundary Fault between the Paleozoic and the Mesozoic Complexes

In the Yasuba-Shirakidani area, the Kamiyakawa Formation (Mesozoic Complex) overlies the tectonic slices of the "Shirakidani Group" and the Agekura Formation (Paleozoic Complex), covering them obliquely underneath it. The thrust fault bounding these two complexes is newly named Agekura Thrust in this paper after Agekura Village where we can observe typical development of the fault (Fig. 12). The Agekura Thrust in the study area generally strikes E-W and dips 30–60° northward. Its trace on the surface is well documented in the study area for more than 15 km, from Gonyu on the east to Hiraishi on the west, though it is occasionally interrupted by faults striking N-S or NE-SW as can be seen in Naro and Shingai (Fig. 3). Although there are some local tectonic modifications in later stages, the thrust almost always dips gently northward. Fault gouge of the thrust is usually less than 5 m in width.

As the Paleozoic and Mesozoic Complexes are extensively distributed in parallel in Kochi Prefecture, further lateral extension of the Agekura Thrust bounding the two units can be clearly traced throughout the northern subbelt in Central Shikoku as shown in Fig. 2, which was compiled after HASHIMOTO (1967), KATTO *et al.* (1961, 1977), ISHIZAKI (1962), HADA *et al.*, (1985), KATTO & KAWASAWA (1958), SUNOUCHI *et al.* (1982), IKUMA (1980). Especially in eastern Kochi Prefecture, the eastern extension of the Agekura Thrust corresponds to the thrust fault which was formerly regarded as the eastern extension of the Gozaishoyama Thrust (IKUMA, 1980) between Cretaceous rocks and the Kamiyakawa Formation. On the other hand, the western extension of the Agekura Thrust is obscure in the north of Mt. Yokokura and Mt. Torigata, but can be detected around the prefectural boundary between Kochi and Ehime, according to the geological information introduced by ISHIZAKI (1962) and TOMINAGA & HARA (1980).

Because the thrust cuts the northern margin of the Cretaceous System in eastern Kochi Prefecture (Fig. 2), it is suggested that the present configuration of the Agekura Thrust reflects post-Cretaceous tectonic movement. Structural features of the primary interface between the Paleozoic and the Mesozoic Complexes (Eo-Agekura Thrust) are still enigmatic.

VII. Primary Depositional Environments of Constituent Rocks of the Paleozoic Complex; Land-bound versus Oceanic

1. General Accounts

As described in the preceding chapters, the Paleozoic and Mesozoic formations in the northern subbelt of the Chichibu Belt are composed of chaotically mixed rocks of numerous kinds. Especially, the Shingai Formation includes abundant exotic blocks that greatly vary not only in age but also in lithology from Late Carboniferous chert to latest Permian terrigenous conglomerate. It is easily understood that these exotic blocks were gathered from various places and intermingled together secondarily, after their individual primary deposition. Thus the primary birthplaces of the individuals should be detected one by one at first, before secondary mixing site and processes of these multigenetic compounds are discussed.

In terms of contained amount of terrigenous coarse clastic grains, these exotic blocks are well classified into two categories, namely land-bound rocks with coarse-grained terrigenous clastics and the oceanic rocks completely free from those (Table 8). The former group comprises sandstone, limestone conglomerate of Type II, greenschist and granitic rocks. Greenschist and granitic rocks are here classified in the land-bound group because they are regarded as land-derived clastic blocks transported directly from land area, even though they themselves are not clastic sedimentary rocks. Besides these, argillaceous materials which share considerable volume in the Paleozoic formations are supposed to have been derived also from land-margin environments. Discussion on argillaceous deposits will be given in chapter VIII in connection with their transport mechanism.

On the other hand, following rocks are constituents of the latter group, namely greenstones, limestone, dolomite, limestone conglomerate of Type I and Type III, chert, acidic tuff and siliceous mudstone. Although some greenstones (volcaniclastic rocks) and limestones (allodapic) contain clastics and rock fragments, all of these constituent grains were derived within their own endemic oceanic realm, in other words, terrigenous clastics are completely excluded from these oceanic rocks.

In this chapter, primary depositional sites of the constituent rocks of the Paleozoic Complex, mainly of the exotic blocks in the Shingai Formation, will be discussed in-

Table 8. Classification of constituents of the Shingai Formation and the "Shirakidani Group".

	land-bound	oceanic
Shingai Formation	sandstone mudstone ls. conglomerate (type II) granitic rocks greenschist	limestone greenstones ls. conglomerate (type I,III) chert acidic tuff sil. mudstone
"Shirakidani Group" Unit I	———	limestone greenstones
Unit II	sandstone mudstone	greenstones chert acidic tuff
Gonyu Formation	sandstone mudstone	greenstones chert dolomite

dividually in comparison with their modern counterparts. In addition, primary depositional site of Unit I of the "Shirakidani Group" will be taken into consideration, because abundant limestone clasts of conglomerates and exotic blocks of limestone contained in the Shingai Formation are supposed to have been derived from limestone of Unit I.

2. Land-bound Rocks

A. Lithology

(1) Sandstone and Limestone Conglomerate of Type II

Limestone conglomerate of Type II and sandstones of the Shingai Formation and Unit II of the "Shirakidani Group" contain abundant coarse-grained clastics. Besides abundant detrital grains of quartz and plagioclase, noteworthy components are rock fragments, pebbles and cobbles of felsic to intermediate igneous and pyroclastic rocks. Especially, pebbles of gabbro and acidic tuff with welding texture are lithologically quite akin to the Mitaki Igneous Rocks and Silurian Okanaro Group, respectively. The latter two are main members of the Kurosegawa Tectonic Zone presently exposed.

(2) Greenschist and Granitic Rocks

As in the case of igneous rock fragments in sandstone and limestone conglomerate, granitic rocks with cataclastic texture forming exotic blocks considerably resemble the Mitaki Igneous Rocks. Also lawsonite-bearing greenschist shows common characters with blueschist in the Kurosegawa Tectonic Zone at Engyoji, Kochi City (MARUYAMA *et al.* 1978) or with greenstones of the Ino Formation (NAKAJIMA *et al.* 1978).

B. Ancient Kurosegawa Landmass and its Detrital Relic

The Kurosegawa Tectonic Zone develops typically in Shikoku Island, running longitudinally in the midst of the Chichibu Belt in E-W direction. Although narrow in width, it displays kaleidoscopic variation in lithology. ICHIKAWA *et al.* (1956) firstly revealed fundamental framework of the zone and discriminated its four major components, namely weakly metamorphosed Siluro-Devonian (Okanaro Group), Mitaki Igneous Rocks, Terano Metamorphic Rocks and serpentinites. Through later researches, further various kinds of rocks such as welded tuff (YOSHIKURA & SATO, 1976) and blueschist (e.g. MARUYAMA *et al.*, 1978; MARUYAMA, 1981), have been supplementarily recognized.

As presented by several authors (KANMERA, 1980; ICHIKAWA & HADA, 1982; MARUYAMA *et al.*, 1984), these various components of the Kurosegawa Tectonic Zone is generally regarded as fragments of an ancient arc or a microcontinent, which were once active during Siluro-Devonian time and finally have collided to the Asian Continent during Jurassic as a huge exotic terrane. Paleolatitudinal trajectory of the Kurosegawa Landmass from Silurian to Cretaceous time has been recently reconstructed on the basis of measurements of paleomagnetism (SHIBUYA *et al.*, 1983; SAKAI & MARUYAMA, 1985). According to these data, the Kurosegawa Landmass had lingered around low-latitude, equatorial zone for a long time until its rapid travel northward in Jurassic time (SAKAI & MARUYAMA, 1985).

On the basis of their similarity to the major components of the Kurosegawa Tectonic Zone, most of the detrital grains and blocks contained in the Paleozoic formations are supposed to have been derived from the ancient Kurosegawa Landmass which was probably exposed subaerially at that time. Judging from this correspondence, therefore, it can be suggested that coarse-grained clastic rocks, namely sandstone and limestone conglomerate (Type II) of the Shingai Formation, sandstone of Unit II of the "Shirakidani Group", and blocks of greenschist and granitic rocks of the Shingai Formation were essentially accumulated and/or emplaced in marginal environments of the ancient Kurosegawa Landmass (arc or microcontinent), which was probably in certain position far south from the "Asian Continent" at that time.

3. Oceanic Rocks

The term "oceanic" is used in this paper to describe an oceanographic condition in which marine waters are too remote to be affected by terrigenous sedimentation around lands with continental crust. Accordingly, oceanic rocks discussed in this section represent those accumulated in environments completely free from sedimentary influx of coarse-grained terrigenous clastics.

A. Limestone and Greenstones

On the basis of its sedimentary texture, limestone of Unit I of the "Shirakidani Group" is suggested to have originated in shallow-water environments, where strong agents, such as wave or stream, worked through all the time. In addition to the dominance of bioclastic and/or oolitic grainstones with sparry calcite, the roundness of most of allochem components indicates considerable high-energy water agitation during their deposition (cf. BATHURST, 1971). Also existence of sponge (*Chaetetes*-like) boundstone points out the development of autochthonous, sessile colonies in that environment, which were somehow resistent against strong water action. Judging from their total volume and wide variation in lithofacies, these limestones are suggested to have formed totally as an organic reef complex or a large-scale limestone mound. All of these limestones are ubiquitously characterized by the complete lack in coarse-grained terrigenous clastic materials. Therefore, their site of deposition was probably isolated from lands for a distance enough to escape from land-margin sedimentary influx.

On the other hand, greenstones underlying above-mentioned reefy limestones are composed of basaltic lavas with pillow structure and volcaniclastics. These mafic volcaniclastics completely exclude coarse-grained terrigenous detritus, such as quartz and granitic rock fragments derived from land areas with continental crust. On the basis of the intimate association with the overlying limestone, they are regarded to have formed as top parts of ancient seamounts which gave pedestals for overlying reef complexes or carbonate mounds.

Thus in the ancient ocean basin developed on the north of the Kurosegawa Landmass (Northern Chichibu Basin) during Early to Middle Permian (+Late Carboniferous), these ancient seamounts (Shirakidani Seamounts) topped by reef or carbonate mound were probably located in a genuinely oceanic realm, considerably isolated from land areas like the Kurosegawa Landmass.

As will be mentioned later, distribution of limestone bodies of similar kind is known in other areas in the Chichibu Belt such as Futagoyama area, Tokyo Metropolis (CHICHIBU RESEARCH GROUP, 1961), Sawadani area, Tokushima Prefecture (KANMERA, 1969), Jiyoshi Pass area, Ehime/Kochi prefectural boundary (SAKAGAMI *et al.*, 1975) and Yayamadake area, Kumamoto Prefecture (KANMERA, 1952). They are probably lateral equivalents of the limestone of Unit I, although individual limestone masses may have independently topped neighbouring seamounts.

B. Limestone Conglomerate (Type I, III)

Limestone conglomerates of Type I and Type III of the Shingai Formation contain numerous limestone clasts, whose characters in lithology and age are mostly common with those of the limestones of Unit I of the "Shirakidani Group". Thus their depositional sites should be directly connected with ancient seamounts capped by reefy limestone.

These limestone conglomerates are characterized by absence of coarse-grained terrigenous clastics, both in clasts and matrices, and by sedimentary textures comparable with those of sediment-gravity-flow deposits. Especially, limestone conglomerate of Type III possesses matrix-supported texture that generally characterizes debris flow deposits. On the contrary, limestone conglomerate of Type I with clast-supported texture may correspond to coarse-grained part of calcareous turbidite, because it occurs with typical allodapic limestone in close association.

Calcareous sediment-gravity-flow deposits were reported from base-of-slope environments along carbonate platform in many cases. Recent examples of these sediments were reported from the Bahama Bank, on which intensive researches by core-sampling and seismic reflection were carried out (e.g. CREVELLO & SCHLAGER, 1980; MULLINS *et al.,* 1984). Since the well-documented study by COOK *et al.* (1972), many studies on ancient carbonate slope have been reported from various areas (e.g. COOK & ENOS, eds., 1977; MCILEATH & JONES, 1978; COOK & MULLINS, 1983). It is generally regarded, therefore, that base-of-slope of topographic high capped by carbonates is the most appropriate environment for emplacement of calcareous sediment-gravity-flow deposits. Especially, calcareous turbidites obtained through DSDP core sampling at Site 446 in Daito Basin (KLEIN & KOBAYASHI *et al.,* 1980; KLEIN, 1985), where is situated on outer franks of isolated seamounts, contain a considerable amount of volcaniclastic grains besides abundant calcareous debris. Limestone conglomerates of Type I are composed exclusively of limestone and greenstone clasts, so that they are almost identical with calcareous turbidites emplaced at base- of-slope around modern seamounts.

As far as the linkage with limestones in Unit I of the "Shirakidani Group" are concerned, limestone conglomerates of Type I and Type III are best explained as ancient base-of-slope sediments accumulated along outskirts of the Shirakidani Seamounts mentioned above during Early to Middle Permian (+partly Late Carboniferous) time.

C. Siliceous Rocks

(1) Stratigraphy and Sedimentation Rate of the Siliceous Rocks in the Shingai Formation

Micropaleontological research revealed that siliceous rocks in the Shingai Formation show wide variation in age ranging from Late Carboniferous to Late Permian. The most remarkable consequence is the recognition of well documented correspondence between their ages and lithologies as shown in Table 3. Namely, chert contains Late Carboniferous and Early to Middle Permian fossils. On the other hand, acidic tuff yields only latest Middle to earliest Late Permian ones and siliceous mudstone solely contains late Late Permian ones. In many cases, these lithologies occur together, intimately related with each other. Especially, it is noteworthy that gradual lithologic change can be observed not only from bedded chert upward into bedded acidic tuff but also from acidic tuff to superjacent siliceous mudstone.

Although these siliceous rocks have been separated into small pieces, the above-mentioned facts indicate that they were successively deposited in situ, changing lithology from chert to siliceous mudstone as time elapsed. Fig. 27 illustrates individual columnar sections of these siliceous rocks arranged in chronologic order and an idealized column synthesized from the formers.

The total thickness of the idealized column (Fig. 27A), roughly estimated to be several tens of meters, appears to be rather thin, though it chronologically covers almost whole Permian Period. Especially, the bedded chert at Loc. 29 provides us with sophisticated information to estimate apparent sedimentation rate. Namely, four radiolarian assemblage zones covering one third of Early Permian, approximately 6 million years estimated from the chronological chart by HARLAND *et al.* (1984), is represented by bedded chert less than 5 m thick at Loc. 29 (Fig. 17). As far as this part is concerened, the apparent sedimentation rate is roughly figured to be 1 mm/1000 years or less. Even if diagenetic compaction is taken into consideration, the primary rate seems to be less than 10 mm/1000 years.

This extraordinarily low sedimentation rate corresponds to those of radiolarites in Alps and Appennine (GARRISON & FISCHER, 1969; BERNOULLI, 1972), one of the representatives of ancient pelagic sediments exposed on land. In the cases of Triassic bedded chert sequences distributed in Southwest Japan, chronologic interval of several ten million years is represented by bedded chert of only 20–50 m in thickness (e.g. ISOZAKI & MATSUDA, 1980a, 1982a; YAO *et al.*, 1980; TANAKA, 1980). Thus apparent average sedimentation rates are estimated to be approximately 1–3 mm/1000 years (=1–3 m/Ma) (ISOZAKI & MATSUDA, 1982b), which are essentially concordant with that of the Permian chert at Loc. 29. In consequence, siliceous rocks of the Shingai Formation are suggested to have been deposited rhythmically and very slowly for more than several ten million years from Late Carboniferous to early Late Permian.

(2) Remarks on Depositional Environment of Bedded Chert

Since the beginning of this century, there has been a great unsettled controversy on

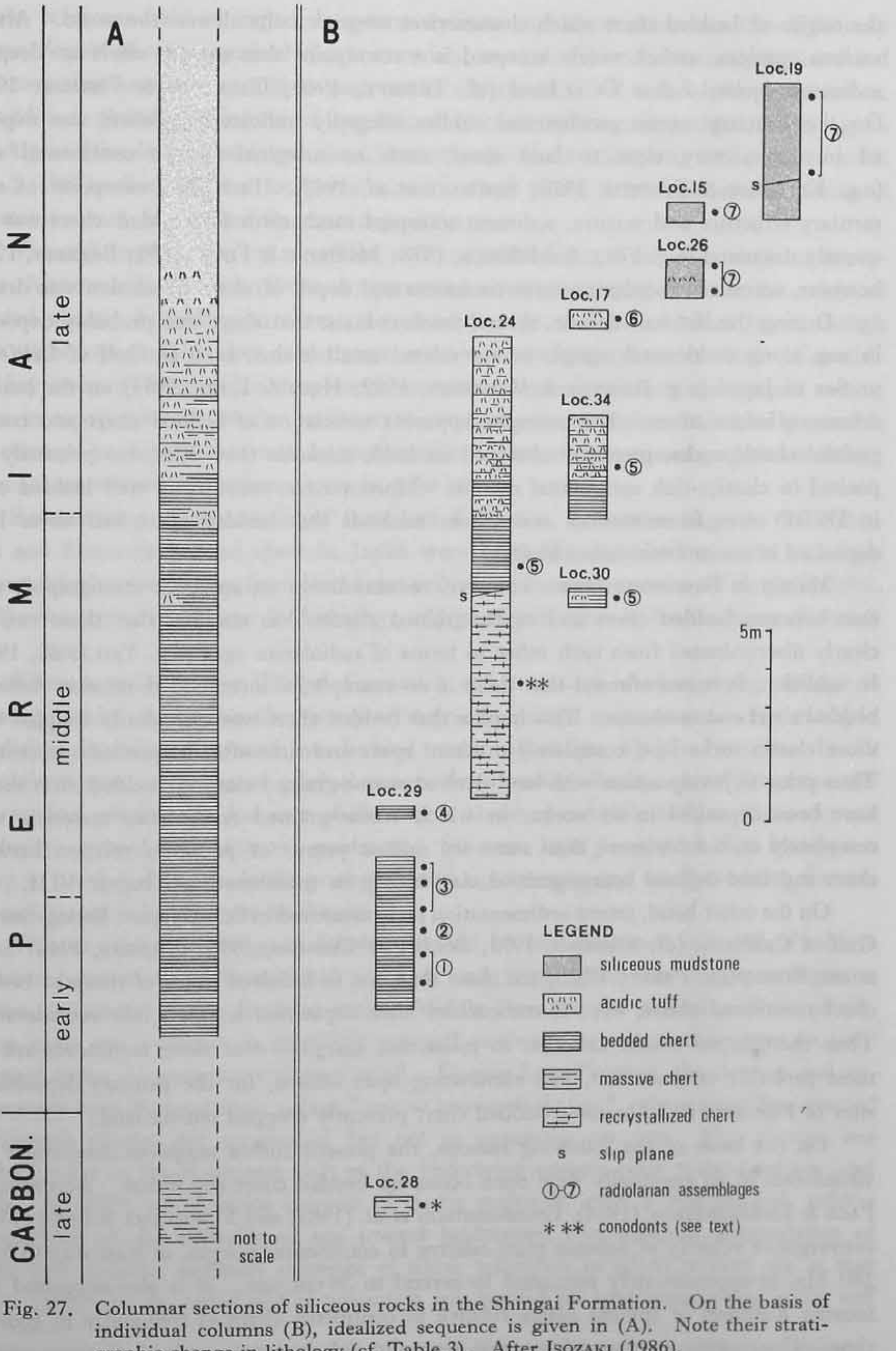


Fig. 27. Columnar sections of siliceous rocks in the Shingai Formation. On the basis of individual columns (B), idealized sequence is given in (A). Note their stratigraphic change in lithology (cf. Table 3). After Isozaki (1986).

the origin of bedded chert which characterizes orogenic belts all over the world. Among various opinions, rather widely accepted is a standpoint that regards chert as deep-sea sediments formed below CCD level (cf. Trümpy, 1960; Garrison & Fischer, 1969). On the contrary, some geochemical studies allegedly indicate that chert was deposited in waters very close to land areas, such as marginal sea or continental shelf (e.g. Kolodny & Epstein, 1976; Sugisaki *et al.* 1982). From the viewpoint of sedimentary structure and texture, sediment-transport mechanism for bedded chert was frequently discussed (e.g. Folk & McBride, 1978; McBride & Folk, 1979; Barrett, 1982), however, no crucial conclusion on environment and depth of chert deposition was drawn.

During the last half decade, several workers insist that chert was probably deposited in seas along continental margin or arc related small basins, such as Gulf of California or Sea of Japan (e.g. Jenkyns & Winterer, 1982; Hein & Karl, 1983) on the basis of erroneous informations. For example, apparent association of bedded chert and coarse-grained clastic rocks, presently observed on land, misleads that chert was primarily deposited in clastics-rich continental margin. Moreover, no recovery of well bedded chert in DSDP cores from modern oceanfloors misleads that bedded chert had never been deposited in ancient mid-ocean basins.

Mainly in Southwest Japan, however, reexamination on apparent stratigraphic relation between bedded chert and coarse-grained clastics has clarified that these two are clearly discriminated from each other in terms of radiolarian ages (e.g. Yao *et al.*, 1980). In addition, it is reconfirmed that there is no example of interbedded relation between bedded chert and sandstone. This implies that bedded chert was secondarily coupled with those clastic rocks in a completely different space and time after its primary deposition. Thus prior to juxtaposition with land-derived coarse-grained clastics, bedded chert should have been deposited in an ocean, in which coarse-grained terrigenous materials were completely ousted for more than some ten million years. *A posteriori* relation between chert and land-derived coarse-grained clastics will be mentioned in Chapter VIII.

On the other hand, recent sedimentation rates measured in Sea of Japan, Bering Sea and Gulf of California (cf. Koizumi, 1975; Scholl & Creager, 1973; Calvert, 1966; Shipboard Scientific Party, 1982), are more than ten to hundred times of those of bedded chert mentioned above, even if compaction after deposition is taken into consideration. Thus there is no crucial criterion to insist that marginal seas along continents are the most probable environment, just eliminating open oceans, for the primary depositional sites of Paleozoic and Mesozoic bedded chert presently cropped out on land.

On the basis of the following reasons, the present author supposes deep-water environments in an essentially wide open ocean for bedded chert deposition. According to Page & Engerbretson (1984), Engerbretson *et al.* (1985) and Maruyama & Seno (1985), convergence velocity of oceanic plate relative to continental margin, at least during latest 180 Ma, is approximately estimated to several to 30 cm/year. It is also suggested that moving direction of ancient plates relative to continents changed frequently in geologic time. Concerning continental margins generally rich in coarse-grained terrigenous materials, it seems hard to expect long-term existence of an environment in which only cherts, devoid of coarse-grained clastic materials, were slowly and constantly accumulated for more than several ten million years under the condition of such rapid plate motion. In addition, global distribution of approximately contemporaneous bedded chert, e.g. in the Alpine-Himalayan chain and the Circum-Pacific chain (GRUNAU, 1965; IIJIMA *et al.* (eds.), 1983), alludes that a fairly vast ocean, whose width is at least several thousand kilometer across, is required for chert deposition.

Through experiments on resolution and recrystallization of siliceous shells of organisms, MINOURA & NAKAYA (1984a, b) presented an interesting opinion on the origin of bedded chert. According to them, considerably wide, deep ocean floor, even though with slight topographic relief, seems most suitable for the original site of chert. Especially, they stressed difference in deep-water movement between modern and ancient oceans. Even in topographically similar basins to the ancient ones, therefore, it is hardly possible for chert to be deposited in well-bedded manner under modern oceanographic condition, in which movement of bottom waters is quite active.

Summarizing above-mentioned facts and discussion, the author suggests that Paleozoic and Mesozoic bedded chert in Japan were primarily deposited in wide and deep oceans, which were remote from land areas and whose bottom waters were rather inactive.

(3) Stratigraphic Change in Lithology and its Significance in Sedimentary Environment

Siliceous rocks in the Shingai Formation exibit vertical or stratigraphic change in lithology, which documents the history of their depositional environment. For example, bedded chert changed upward into bedded acidic tuff in late Middle Permian. In the transitional part, up-sequence gradual change from purely siliceous chert into more tuffaceous one, via interbedded part of the two is observed. Acidic tuff, in turn, changes gradually upward into siliceous mudstone. Siliceous layer / mudstone film interface is sharp in bedded chert, gradually getting obscure upsequence, and finally bedding features almost disappear in siliceous mudstone.

This stratigraphic change in lithology should be best explained in terms of relative distance between their depositional site and land areas which can supply terrigenous clastics. Namely, during Early to middle Middle Permian, the depositional site of siliceous rocks was probably in genuinely pelagic* environment, where there was no sedimentary influx of terrigenous clastics at all. During Late Permian, the depositional environment have changed from pelagic* one to hemi-pelagic one*, where some fine-grained terrigenous clastics did accumulate but not in significant amount. This change was probably due to the horizontal shift of the underlying oceanic plate toward certain land areas. In short, up-sequence increase of clastic materials, even if fine grained, reflects approaching of the depositional site toward landmasses. In addition, intercalation of acidic tuff probably indicates existence of silicic volcanism in island or land arc at that time. Although the initial site of volcanism was located on land areas, vitric acidic tuff

* Terminology of pelagic and hemi-pelagic is after BERGER (1974) and STOW & PIPER (1984).

free from terrigenous clastics was deposited on ocean floors remote from land areas after aerial transportation.

Similar stratigraphic change of siliceous rocks has been recently reported also from Taishaku and Akiyoshi areas (Isozaki, 1984; Kanmera & Sano, 1985) in the Chugoku Belt, Azusagawa area in the Mino Belt (Otsuka, 1985) and Sakawa area in the southern subbelt of the Chichibu Belt (Matsuoka, 1984).

D. Lateral Facies Change among Oceanic Rocks

Since above-mentioned siliceous sediments and calcareous ones both chronologically range from Late Carboniferous to Late Permian, it is evident that they were formed simultaneously as mutual lateral equivalents in an oceanic realm, which was isolated from

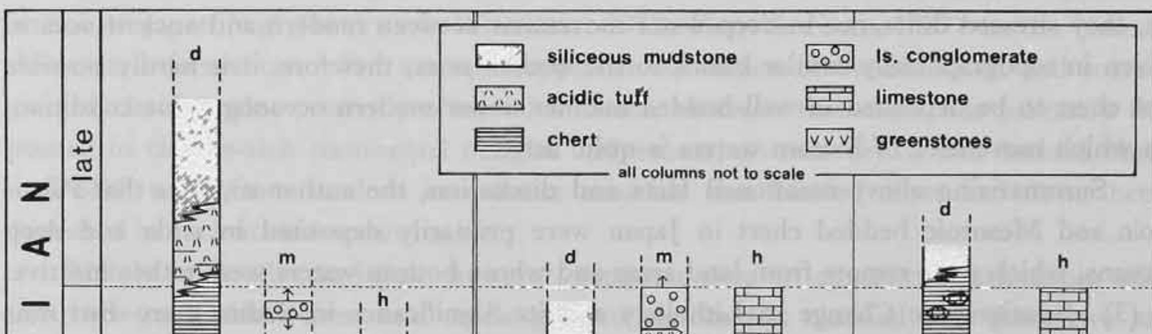


Fig. 28. Geologic columns showing lateral lithologic change of oceanic sediments in the Shingai Formation (A), from deep-water sequence (d) to that of topographic high (h) via marginal sequence along base of slope (m). After Isozaki (1986). For comparison, those sequences in Taishaku (B) and Akiyoshi (C) areas are also shown. For further details, see following references; Yasuba-Shirakidani area: Fig. 27A in this paper, Isozaki (1980a, b, 1985), Katto & Kawasawa (1958), Taishaku area: Isozaki (1984), Oho *et al.* (1985), Hase *et al.* (1974), Akiyoshi area: Kanmera & Nishi (1983), Kanmera & Sano (1985), Uchiyama *et al.* (1986), Ota (1977), (+pers. commun. from K. Kanmera in 1986).

land areas. As mentioned above, limestones and limestone conglomerates were probably deposited on the ancient Shirakidani Seamounts and along their base-of-slope, respectively. On the other hand, siliceous sediments are considered to have been deposited extensively on deeper seafloor, surrounding topographic irregularities like seamounts.

Intimate association of interbedded limestone/chert with limestone conglomerate of Type III at Loc. 3 (cf. Fig. 7B) may allude a gradual lateral change of depositional facies. Stratigraphic columns of siliceous rocks and limestone conglomerates in the Shingai Formation and limestone of Unit I of the "Shirakidani Group" are summarized and juxtaposed side by side in Fig. 28A to demonstrate lateral facies change among these rocks.

In Akiyoshi and Taishaku areas, the Inner Zone of Southwest Japan, siliceous rocks and calcareous rocks, of the similar kinds to those in the Yasuba-Shirakidani area, are distributed and they are chronologically and lithlogically identical to those in the Shingai Formation. As KANMERA (1983) mentioned, these sediments show similar pattern of lateral facies change (KANMERA & NISHI, 1983; HASE *et al.* 1974; ISOZAKI, 1984). Among them, Permo-Carboniferous rocks in the Taishaku area display the best example for development of the tripartite facies, namely facies of the shallow-water, the slope-margin and the deep-water, and their mutual relation in lateral extent. For comparison, stratigraphic columns obtained from both Taishaku and Akiyoshi areas are shown in Fig. 28B, C. Especially it is noteworthy that the lowermost siliceous rocks rest directly upon basaltic volcaniclastics in the Akiyoshi and Taishaku areas (UCHIYAMA *et al.*, 1986; GOTO & ISOZAKI, 1986).

On the basis of the above-mentioned comparison with modern and ancient counterparts, primary spatial arrangement of the oceanic rocks of the Paleozoic Complex in the Yasuba-Shirakidani area is schematically reconstructed as illustrated in Fig. 29. Information concerning the basement of these siliceous rocks is not sufficient enough in

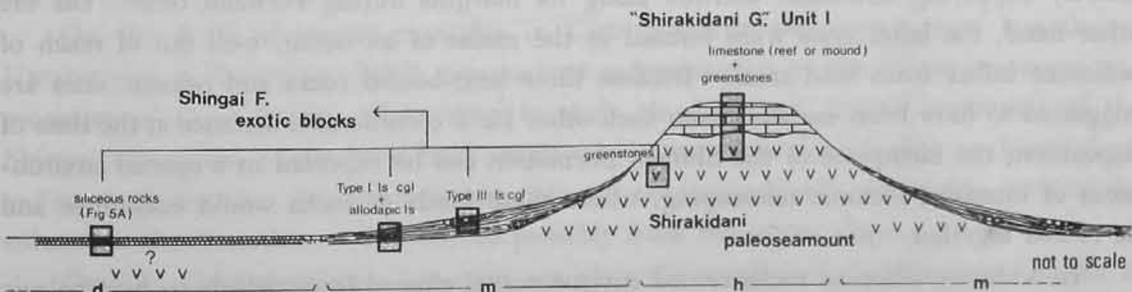


Fig. 29. Reconstruction model for primary depositional environments of oceanic sediments, presently emplaced in the Shingai Formation as exotic blocks. Abbreviations d, m and h represent deep-water facies, marginal facies and that of topographic high, respectively (cf. Fig. 28). After ISOZAKI (1986).

Shikoku. However, on the basis of analogous examples in Akiyoshi and Taishaku areas, it is suggested that the siliceous rocks were probably underlain by basaltic rocks representing the upper oceanic crust. At present, even though lithofacies varies owing to topographic relief, all of these oceanic rocks can be regarded to have deposited on the same ancient oceanic plate (Shirakidani Plate), which underlay the Northern Chichibu Basin on the north of the Kurosegawa Landmass. The most promising candidate for the above-mentioned Permian oceanic plate may be the southern part of the Farallon Plate, which was in contact with the southeastern margin of Asia during Permian time (Maruyama & Seno, 1985).

VIII. Secondary Mixing Processes of the Paleozoic Complex

According to the aforementioned discussion in modern aspects, the Paleozoic Complex is newly regarded as admixture of ancient land-bound and oceanic rocks. Judging from its lithologic assemblage, the Mesozoic Complex is also fairly explained in the same way. This chapter focuses on their mixing sites and mixing processes, exemplifying the Shingai Formation and the "Shirakidani Group" as sedimentarily mixed products and tectonically mixed ones, respectively.

1. Sedimentary Process and Site of Emplacement of the Shingai Formation

Judging from its sedimentary features and origin of individual constituents, the Shingai Formation is best interpreted as a product in a trench and its environs in a convergent plate boundary at end-Permian. In this section, sedimentary process that worked to mix up the above-mentioned land-bound and oceanic rocks will be discussed with special reference to the birthplace of the Shingai Formation.

A. Mixing of Land-bound and Oceanic Materials

As described in chapter VII, the Shingai Formation contains exotic blocks of both land-bound and oceanic rocks. On the basis of similarity in lithology, the former ones are supposed to have their origin in the ancient Kurosegawa Landmass, which had been actively supplying abundant detritus along its margins during Permian time. On the other hand, the latter ones were formed in the midst of an ocean, well out of reach of sediment influx from land areas. Because these land-bound rocks and oceanic ones are suggested to have been isolated from each other for a considerable distance at the time of deposition, the birthplace of the Shingai Formation can be expected in a special environment of intensive tectonic telescoping, where these kinds of rocks would encounter and be mixed together.

In addition, siliceous rocks record environmental change from pelagic to hemipelagic durnig Late Permian in terms of upward increment of argillaceous materials. This phenomenon probably reflects gradual shortning of the horizontal distance between certain landmass and the depositional sites of siliceous sediments. Similar pattern of time-dependent change in content of terrigenous materials can be recognized in limestone conglomerates of the Shingai Formation. Namely, conglomerate of Type II carries not only Late Permian fossils, the youngest fossils contained in the conglomerates, but also coarse-grained clastics derived from the Kurosegawa Landmass, while those of Type I and Type III contain neither Late Permian fossil nor Kurosegawa-derived clastic grains.

These facts totally imply that oceanic sediments had been shifted laterally from mid-ocean environment to land margin of the ancient Kurosegawa Landmass.

B. Sedimentary Process of the Shingai Formation

The Shingai Formation is composed mainly of pebbly mudstone with abundant clasts and blocks of various sizes from pebble to huge block of over 20 m in diameter. Generally, these clasts and blocks are enveloped in the surrounding mudstone without any sheared or disturbed features on contact planes between them. In addition, mudstones themselves do not possess remains of high-grade metamorphism, tectonic modification or flow of matrices under high confining pressure (cf. CLOOS, 1982, 1983). Judging from these facts, rocks of the Shingai Formation are regarded as products of certain sedimentary processes that worked essentially at sediment/water interface. Especially, matrix-supported fabric, ill-sorting and random arrangement of various clasts and blocks are compared to characteristics of sediments transported by large-scaled debris flow or slumping.

Hence pebbly mudstone of the Shingai Formation is regarded to have deposited in an environment near slopes, where sediment transport mechanisms of these kinds would be easily initiated, mainly due to gravitational instability of high potential energy. Owing to secondary tectonic disturbance, however, it is difficult to reconstruct the geometry of paleoslopes in which sediment-gravity-flows were triggered.

C. Birthplace of the Shingai Formation

As in the case in Bassin Slide in Sunda Arc discussed by MOORE *et al.* (1976), trench and its environs in a subduction zone, especially trench inner wall with steep slopes, can fulfill the necessary conditions for emplacing large amount of slumping and/or debris flow deposits. Therefore, the birthplace of the Shingai Formation is possibly expected in a trench and its environs of an ancient convergent plate boundary between the Kurosegawa Landmass (arc or microcontinent) and the Shirakidani Plate (=Farallon? or unknown one) at the end-Permian.

On the basis of recent examples in Circum-Pacific convergent plate boundaries, UNDERWOOD & BACHMAN (1982) summarized sedimentation in trench environments and geometry of those basins. According to their classification, chaotic sediments of the Shingai Formation might have been emplaced in immature slope basins on lower slope or "starved" trench. Argillaceous materials and sandstone blocks, occupying most of the volume of the formation, were derived possibly from the upper slope.

Oceanic rocks contained, however, are generally small and they occur as blocks of mostly less than several meters in diameter. In some case, blocks of sandstone of several meters in diameter contain smaller lenses or blocks of chert within them. These oceanic blocks might have undergone a recycle process in which oceanic materials once accreted landward were brought back to trench or lower slope basins by collapsing of walls of trench inner slope and were redeposited with younger sediments (cf. COWAN & PAGE, 1975).

During the latest decade, various models for accretion/mixing process around trench and its environs have been proposed. Synthesizing these various viewpoints, MOORE *et al.* (1985) and COWAN (1985) illustrated an idealized cross section of a subduction zone, showing multi-street mixing processes. The Shingai Formation evidently lacks remains of high-grade metamorphism and/or severe tectonic disturbance, which are expected in the deeper levels of a subcluction zone. Among the processes mentioned above, therefore, those working at superficial level may be suitable for the mechanism that emplaced the Shingai Formation.

Also for the clastic rocks of Unit II of the "Shirakidani Group", the interpretation on depositional site of the Shingai Formation may be fundamentally applied, although the former underwent severer tectonic event than the latter in later stage.

2. Genesis of Tectonic Slices of the "Shirakidani Group"

A. Fundamental Tectonic Setting

The "Shirakidani Group" is characterized with its remarkable structure composed of piled tectonic slices and is clearly discriminated from other geologic units in this area by having huge amount of oceanic rocks. Concerning rock association, however, the "Shirakidnai Group" shares almost the same materials with the Shingai Formation, e.g. reefy limestone, greenstones and siliceous rocks as oceanic constituents, and sandstone and mudstone as land-bound ones. From the viewpoint of constituent materials, both of the "Shirakidani Group" and the Shingai Formation are supposed to have formed fundamentally in the same tectonic setting in a subduction zone, where mixing of land-derived materials and oceanic ones was under way. Especially, Unit II possesses common features with the chaotic deposits of the Shingai Formation, which was presumably accumulated in a trench and its environs of the subduction zone.

Although they share the same constituent materials, two distinct modes of occurrence, i.e. olistostromal admixture and tectonic interlayering of land-bound and oceanic rocks, suggests essential duality in their mixing process. To build the tectonic slices of the "Shirakidani Group", a certain kind of tectonic process is required that can slice land-bound and oceanic rocks into thin but kilometer-long tectonic slivers, shuffle thems several times and finally pile them up.

B. Landward Accretion of a Large Amount of Oceanic Rocks

As far as mode of occurrence of oceanic rocks is concerned, several differences can be recognized between the Shingai Formation and the "Shirakidani Group" as follows.

First and the most important point is difference in the size of oceanic rocks. As shown in the geologic map, individual body of greenstones or limestone of the "Shirakidani Group", both Unit I and Unit II, can be recognized as mappable unit, generally more than 3 km in length and 200 m in width. On the other hand, those contained in the Shingai Formation are mostly less than several meters in diameter.

Second point is juxtaposition of huge bodies of oceanic rocks (Unit I) and those with coarse-grained terrigenous clastics (Unit II) of the "Shirakidani Group", approximatey even-balanced in volume. Ubiquitous development of tectonic interfaces between slices, with intercalation of small serpentinite bodies, indicates that their juxtaposition was led mainly through tectonic process. For example in the north of Shirakidani, tectonic slices of Unit I and Unit II interlayer each other more than three times for each.

Third is the pervasive development of fissile features in argillaceous rocks that culminated in the semi-schistose unit, the Agekura Formation. Besides semi-schists of the Agekura Formation, mudstones of the tectonic slices are sheared more intensively than those of the Shingai Formation.

On the basis of the above-mentioned facts, the tectonic slices of the "Shirakidani Group" can be regarded as tectonic prisms or wedges, that were accreted landward through subduction of the Shirakidani Plate underneath the ancient Kurosegawa Landmass. Although present (apparent) tectonic vergence of these tectonic slices is toward south, being opposite to the proposed subduction direction, this is supposed to be due to secondary tectonic deformation in later stage, probably after Cretaceous time. Because latest Middle to earliest Late Permian radiolarians obtained from an exotic block are the youngest among the fossils from the "Shirakidani Group", these tectonic slices are supposed to have been formed in Late Permian or later.

Although actual process that built piled tectonic slices has not been fully clarified yet, some models proposed for modern arc-trench system can be positively applied to the case of the "Shirakidani Group". On the basis of seismic reflection data, HILDE & SHARMAN (1978) and HILDE (1983) proposed an idea that horst and graben structure in outer trench wall plays an important role in trench sediment subduction. Lately, studies on the recent subduction zone off Mexico by MOORE *et al.* (1981) revealed that most of the oceanic sediments are subducted downward and some of them are later underplated to the overriding plate, while land-derived trench sediments are off-scraped and accreted landward. As in the case of these studies, huge bodies of oceanic rocks of the "Shirakidani Group" were probably accreted not through off-scraping at toe of trench inner slope but through underplating (subcretion) in much deeper level. According to MOORE *et al.* (1981), metamorphism in the depth of underplating would corresponds to zeolite to pumpellyite-prehnite facies. The sedimentary mixing to form Unit II in and around trench environs naturally predates the underplating.

In conclusion, the author comprehend that the tectonic slices of the "Shirakidani Group" was formed in a subduction zone mainly through underplating process in the deeper level, but not so deep enough to suffer high-pressure metamorphism. This interpretation may be applied to the Gonyu Formation, which is characterized by the juxtaposition of terrigenous clastics and thick bedded chert with dolomite as oceanic rocks.

IX. Permian Conglomerate-bearing Formations in the Chichibu Belt and Their Geological Connotation

In this chapter, from the modern aspect on convergent plate boundary tectonics, the author tries to re-evaluate the geological significance of the well-known Permian conglomerate-bearing formations around the Kurosegawa Tectonic Zone.

In terms of fusulinid biostratigraphy, KANMERA (1953) summarized distribution and lithologic characters of the Permian conglomerate-bearing formations in Japan. Since then, the Kuma Formation (KANMERA, 1953) in Kumamoto Prefecture and the Shingai Formation (formerly Yasuba F.) had long been regarded as typical representatives of "Late Permian conglomerate facies" in the Chichibu Belt. Through comparison between the Kuma and the Shingai Formations, it is proposed here that the two formations differ from each other considerably in various aspects. This difference implies that the two represent mutually distinct two sedimentary environments. Furthermore, other conglomerate-bearing Permian formations in the Chichibu Belt are well divided into two types, i.e. Kuma-type and Shingai-type. At first, differences between these types from various aspects are mentioned and next their significance on the tectono-sedimentary history in the northern margin of the ancient Kurosegawa Landmass is discussed.

1. Shingai Formation versus Kuma Formation

Comparing the Kuma and the Shingai Formations, the author recognized following critical differences between them, which are listed in Table 9. All descriptions for the Kuma Formation cited in this chapter are derived from the paper by KANMERA (1953), while those for the Shingai Formation can be referred in preceding pages.

At first, limestone conglomerates of the two formations differ from each other both in lithology and fossil content. Limestone conglomerates (or conglomeratic limestones) of the Kuma Formation, developed in several horizons, are rather monotonous and characterized by abundant coarse-grained terrigenous clastics. On the contrary, Yasuba limestone conglomerates show wide variation in lithology. Namely, some are characterized by complete lack in coarse-grained terrigenous clastics (Type I and Type III), while others contain abundant terrigenous materials (Type II). Thus, the limestone conglomerate of Type II solely has some common characters in lithology with the Kuma conglomerates. In the Kuma Formation so far as reported, there is no counterpart of limestone conglomeartes of Types I and Type III of the Shingai Formation.

It is also noteworthy that the occurrence of Late Permian fusulinid, *Lepidolina*, is limited to Type II conglomerates which is contained as an exotic block in the Shingai Formation. The Kuma conglomerates are characterized exclusively by *Lepidolina kumaensis* fauna without any older elements, while Type II conglomerates of the Shingai Formation differ from the Kuma conglomerates in carrying not only *Lepidolina* but also older fusulinids such as *Triticites* and *Neoschwagerina*.

Second, the Kuma conglomerates are autochthonous units, conformably intercalated in bedded sandstone and mudstone. On the other hand, the Yasuba conglomerates are exotic (allochthonous) blocks contained in surrounding pebbly mudstone.

Third, exotic blocks of oceanic rocks such as greenstones, reefy limestone or chert are common in the Shingai Formation, while the Kuma Formation completely excludes these kinds of exotic blocks. Therefore, it is pointed out that almost all of components forming the Kuma Formation are detected in the Shingai Formation, but not vice versa.

Fourth, from mudstone of the Kuma Formation, Late Permian radiolarians were obtained (MIYAMOTO *et al.* 1985), which are consistent in age with fusulinids from the

Table 9. Comparison between the Shingai and the Kuma Formations.

		Shingai Formation	Kuma Formation
limestone conglomerate			
	mode of occurrence	allochthonous	autochthonous
	lithology	rich in coarse terrigenous clastics (type II) free from coarse terrigeneous clastics (type I,III)	rich in coarse terrigenous clastics --------
	fossil content	several assemblages mixed	L. kumaensis Assemblage
Stratigraphy		olistostromal	normal (well organized)
Exotic blocks		sandstone, greenstones, limestone, ls. conglomerate chert, acid. tuff, sil. mudstone, granitic rocks, greenschist,	--------
Age		latest Permian ---	Late Permian
Site of emplacement		trench/lower slope basins	upper slope/ fore-arc basins
Lithologic equivalents		Hisone G.(Mid.Perm.) Ichinose G. Takaoka G.(Mid.Perm.) Doi G. Miyama F.	Haigyu G. Mizukoshi F. Kozaki F.(Mid.Perm.)

Kuma conglomerates. In the Shingai Formation, however, nearly the same kind of radiolarians are found in exotic blocks of siliceous mudstone and the age of the formation is expected to be younger than that. Thus the Shingai Formation is suggested to have deposited at least later than the Kuma Formation.

In summary, the most essential difference between the Shingai and the Kuma Formations lies in their stratigraphic features; i.e. the chaotic olistostromal nature of the former against the well-organized stratigraphic character of the latter. Judging from the difference in age and containing materials, it is evident that the Kuma Formation was deposited in an environment quite different from that of the Shingai Formation and that the deposition of the former took place before the emplacement of the latter in end-Permian.

2. Equivalents of the Shingai and the Kuma Formations.

As mentioned by Kanmera (1953) and Ichikawa *et al.* (1956), so-called Permian formations characterized by conglomerate are sporadically distributed along the Kuroesgawa Tectonic Zone in the midst of the Chichibu Belt (Fig. 30). By applying the same criteria for distinction between the Shingai and the Kuma Formations, these formations can be classified into following two categories, namely Shingai-type ones, the equivalents of the Shingai Formation, and Kuma-type ones, those of the Kuma Formation, as listed in Table 9.

A. Shingai-type Formations

Following formations are referred to the Shingai-type ones; the Hisone Group (Hirayama *et al.* 1956) in Tokushima Prefecture, a part of the Ichinose Group (Katto *et al.* 1956) and a part of the Takaoka Group (Suyari, 1961) in Kochi Prefecture, a part of the Doi Group (Ichikawa *et al.* 1954; Hada, 1974) in Ehime Prefecture and the Miyama Formation (Miyamoto *et al.*, 1985) (=a part of the Kakisako Formation, Kanmera, 1952) in Kumamoto Prefecture. All of these formations are composed mainly of pebbly mudstone with certain amount of exotic blocks of greenstones, reefy limestone and siliceous rocks. Besides Permian fusulinids from limestones, Permian radiolarians have been recently extracted from the siliceous rocks (Sato & Matsuda, 1981; Nakatani, 1982; Miyamoto *et al.* 1985; Ishida, 1985). On account of their lithologic characters and approximate age assignment, these strata are suggested to have been emplaced in a tectono-sedimentary condition akin to that of the Shingai Formation. Most of these units are tectonically separated from surrounding geologic bodies by faults, but the Hisone Group is covered unconformably by Late Triassic shallow-marine sediments (Ichikawa *et al.* 1953). Hence, emplacement of these formations are supposed to have been completed before Late Triassic.

B. Kuma-type Formations

On the other hand, the Haigyu Group (Hirayama *et al.* 1956) in Tokushima Pre-

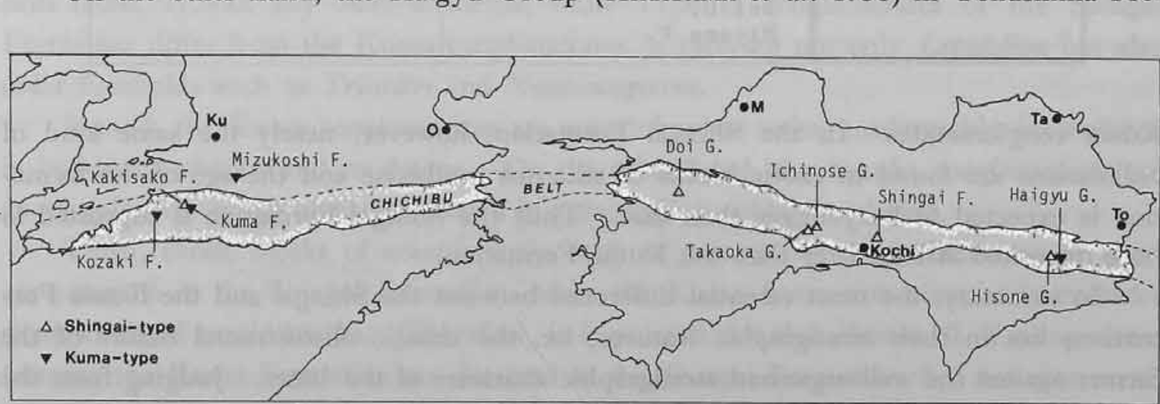


Fig. 30. Distribution of lithologic equivalents of the Shingai and the Kuma Formations in the Outer Zone in Shikoku and Kyushu, Southwest Japan.

fecture, the Kozaki Formation (KANMERA, 1961) and Mizukoshi Formation (MATSUMOTO & FUJIMOTO, 1938; YANAGIDA, 1958) in Kumamoto Prefecture are regarded as representatives of the Kuma-type ones. In general, they are well-organized stratigraphic units without showing olistostromal features. These units consist solely of land-bound clastic sediments, namely interbedded sandstone, conglomerate and mudstone, and lack exotic blocks of oceanic rocks.

Most of the limestones in clast and/or matrix of these conglomerates have muddy composition, while limestones of typical reef origin are totally absent from these formations. Each formation is essentially characterized by a particular fauna of its own without contamination of older elements. Thus these formations possess common features with the Kuma Formation. The Middle Permian Kozaki Formation is covered unconformably by the Late Triassic shallow marine sediments (KANMERA, 1961), so that pre-Late Triassic emplacement of these formations is ascertatined.

3. Tectono-sedimentary Framework of the Late Permian Conglomerate-bearing Formations

Permian formations characterized by coarse-grained clastics are usually developed in close association with the Kurosegawa Tectonic Zone. These formations of the Shingai-type and the Kuma-type respectively represent certain tectono-sedimentary regimes within an ancient arc-trench system.

As described in foregoing pages, the Shingai Formation is suggested to have formed in trench/slope basins of an ancient subduction zone, on the basis of their chaotic sedimentary features. The Shingai-type formations are probably the same in origin.

On the other hand, the Kuma Formation and its equivalents have well-organized normal stratigraphy without any exotic elements of oceanic origin. Generally speaking, contamination of oceanic rocks into terrigenous clastics may imply the proximity to the trench axis, where sedimentary mixing occurs most effectively. The depositional sites of the Kuma-type formations, therefore, are supposed as environments where exotic blocks of oceanic origin are seldom or never carried in. From sedimentological aspect, MAEJIMA (1979) insisted that the Haigyu Group, one of the Kuma-type sequence, had been deposited as a part of an ancient submarine-fan. As far as modern analogues are concrened, possible candidates for depositional environments of the Kuma-type formations are fore-arc basin and mature/immature slope basin on upper slope (UNDERWOOD & BACHMAN, 1982) of an ancient subduction zone.

Synthesizing these discussions, the present author proposes that both of these two types of formations were formed in an ancient arc-trench system developed along the northern margin of the Kurosegawa Landmass around end-Permian time. The Shingai-type formations are possibly compared with modern sediments in trench to lower slope basins and the Kuma-type ones with those in upper slope basins to fore-arc basins, respectively. Sedimentation and emplacement of these formations should have been carried out mainly around the end-Permian, well prior to unconformable deposition of Late Triassic shallow-marine clastics.

X. End-Permian Tectonic Framework along the Northern Margin of the Kurosegawa Landmass

1. Paleozoic Complex as Subduction-related Products

Foregoing chapters of this paper provide a basis for reconstructing the tectonic framework of the northern margin of the Kurosegawa Landmass around end-Permian time. From various aspects described above, the tectono-sedimentary regime of a convergent plate boundary is the preferred birthplace of the formations of the Paleozoic Complex (Chapter III) presently distributed in and around the Kurosegawa Tectonic Zone. Judging from the following constraints, these formations compare favorably with the products in modern convergent plate boundaries, especially with those in subduction zones.

The first point is that the formations of the Paleozoic Complex are made up of both oceanic and land-bound rocks, primarily formed in fairly isolated environments from each other. Large-scale horizontal shortening in crustal surface is required to explain the mixing of these materials. Only convergent plate boundary can be practically responsible for this kind of large-scaled mixing of oceanic and land-bound rocks.

The second point is the upward increase of terrigenous materials recognized in the oceanic sequences which begin with rocks of pelagic origin. As shown in the geologic columns of the oceanic rocks (Fig. 27), stratigraphic change in lithology documents an environmental change of depositional site, from pelagic to hemipelagic. This phenomenon can be explained by gradual access of their depositional sites to a certain landmass with continental crust, which can supply terrigenous clastics in considerable amounts. Subduction zone is the most promising and suitable tectonic setting that can provide such access of depositional site in successive manner for a long time span. Under this scheme, constant subduction process went on until the Shirakidani Seamounts reached to the trench along the northern margin of the Kurosegawa Landmass in latest Middle Permian.

The third point is the occurrence of the high-pressure type metamorphic rocks from neighbouring areas with ages (208–240 Ma) related to the above-mentioned geologic process (MARUYAMA *et al.* 1978), that suggests subsequent subduction along the ancient Kurosegawa Landmass around that time.

2. A Model for Late Permian Subduction along the Northern Margin of the Kurosegawa Landmass

Judging from the present configuration of Southwest Japan, the Shirakidani Plate (underlying Permian Northern Chichibu Basin) was probably located between the Kurosegawa Landmass to the south and the Sino-Korean Landmass (including the Hida Terrane) to the north.

Paleomagnetic data by SHIBUYA *et al.* (1983) and SAKAI & MARUYAMA (1985) indicate that the Kurosegawa Landmass is supposed to have been lingering around equatorial areas for a long time from Silurian to early Late Jurassic until its rapid travel northward in latest Jurassic. In addition, the Shirakidani Seamounts, topped with well-developed reefy limestone are supposed to have been situated in a low-latitude oceanic regime, because modern organic reefs can flourish exclusively in tropical to subtropical seas. Therefore, the interaction between the Shirakidani Plate and the Kurosegawa Landmass, i.e. the formation of the Paleozoic Complex, probably took place in low-latitude areas.

The present configuration of the Paleozoic Complex and the Kurosegawa elements in the Chichibu Belt suggests that the Shirakidani Plate had been subducting southward underneath the Kurosegawa Landmass during the Permian (+Late Carboniferous). Namely, the Permian conglomerate-bearing formations are presently distributed mainly to the north of major tectonic lenses of the Kurosegawa Tectonic Zone. In addition, Late Carboniferous to Permian reefy limestones almost always crop out along the northern margin of the Kurosegawa Tectonic Zone from Kanto (Chichibu Research Group, 1961) to Kyushu (Kanmera, 1952). Accordingly, the assumed Permian subduction zone is here newly designated as Northern Kurosegawa Subduction Zone.

As mentioned before, sedimentary mixing of the oceanic and land-derived materials of the Paleozoic Complex were carried out mainly by gravity-induced debris flows, that left olistostromal deposits in lower slope basins and/or trench floor. The chaotic rocks of the Shingai Formation and Unit II of the "Shirakidani Group" are supposed to have formed primarily in superficial levels in the framework of the Northern Kurosegawa Subduction Zone. Besides, in fore-arc and/or upper slope basins, somehow isolated landward from trench, terrigenous clastic rocks were deposited mostly as turbidites. The Kuma Formation and its equivalents excluding oceanic materials are good representatives of such kind of sedimentary facies.

Voluminous landward mass accretion in this subduction zone, however, was probably accomplished through tectonic processes, such as off-scraping and underplating at much deeper levels. Especially in the case when topographic irregularities, such as seamounts or rises, reach the subduction zone, extraordinary landward accretion of huge amount of oceanic materials would particularly take place by virtue of their buoyancy, in contrast to lesser accretion during normal subduction. Tectonic slices of the "Shirakidani Group" fit in with these imbricated tectonic wedges formed mainly through underplating. With the arrival of the Shirakidani Seamount (chain) at the trench outer swell, some of the reefy limestones and greenstones forming its upper part would have collapsed down and their debris would have been delivered to the trench and its environs to be scraped off into accretionary wedges or to be subducted together with trench sediments. Remnants of the seamounts would have subducted to deeper level and successively been peeled off to be underplated to the overriding wedges.

In the deepest domain of the subduction zone, on the other hand, high-pressure metamorphism is supposed to have been under way. Crystalline schists of the Agekura Formation, blueschist at Engyoji (Maruyama *et al.*, 1978) and those of the Ino Formation (Nakajima *et al.* 1978) may correspond to the subduction-related high-pressure metamorphic rocks.

Summarizing tbe foregoing speculations, the end-Permian Northern Kurosegawa

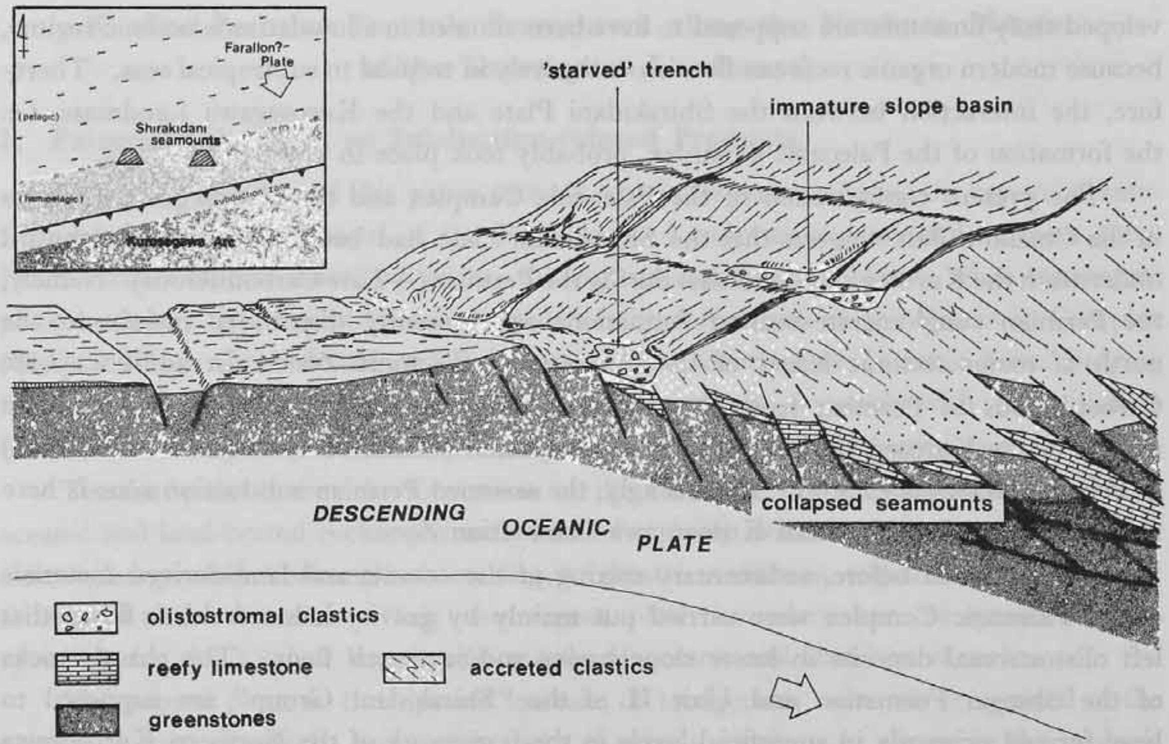


Fig. 31. Schematic diagram showing the end-Permian Northern Kurosegawa Subduction Zone between the Shirakidani Plate and the Kurosegawa Landmass.

Subduction Zone is schematically reconstructed, as illustrated in Fig. 31.

The present southward tectonic vergence of the Paleozoic Complex appears to be the opposite to the direction of the above-mentioned Northern Kurosegawa Subduction Zone. However, post-Cretaceous deformations have overprinted to obscure the primary structures of the Paleozoic Complex. IKUMA (1980) investigated tectonic behavior of the Gozaishoyama Thrust, the boundary fault between the Cretaceous and the pre-Cretaceous rocks in the east of the Yasuba-Shirakidani area. He revealed that the post-Cretaceous shortening in N-S direction with southward tectonic vergence made even the surface of the unconformity between the Gonyu Formation and Cretaceous rocks overturned to dip north. It is easily understood, therefore, that units of the Paleozoic Complex underlying the Cretaceous rocks should have undergone the similar tectonic modification to change their dipping direction.

3. Duration of Subduction and the Acme of Landward Accretion

Subduction process between the Shirakidani Plate and the Kurosegawa Landmass is regarded to have continued through Permian (+Late Carboniferous). On the other hand, formation of the Paleozoic Complex, i.e. mixing of Late Carboniferous - early Late Permian rocks of various origins and their landward accretion should have been completed by the end of Middle Triassic at the latest, because the Paleozoic Complex is in part covered unconformably by the Late Triassic Kochigatani Group (ICHIKAWA *et al.*, 1953; KANMERA, 1961). Thus duration of active accretion is roughly limited to Late Permian to middle

Triassic. Judging from the facts that the Paleozoic Complex is completely free from Tirassic fossils and that reefy limestones ceased long-term, successive sedimentation at the end of Middle Permian, the author speculates that the landward accretion culminated in Late Permian, when the Shirakidani Seamounts (chain) reached the Northern Kurosegawa Subduction Zone. If the seamount chain collided obliquely against the Kurosegawa Landmass, the *ne plus ultra* of the accretion may have shifted laterally along the plate boundary.

Subduction around that time is also inferred by occurrence of blueschist with radiometric (K-Ar) age of 208–240Ma, i.e. Middle-Late Triassic (MARUYAMA *et al.*, 1978), which is regarded to represent not the age of metamorphism itself but that of later uplift i.e. the release from the site of metamorphism. Micaceous sediments of the Upper Triassic Kochigatani Group may mark the timing of uplift and subaerial exposure of these schists. Hence the subduction process with high-pressure type metamorphism which precedes its uplift is inferred to have been under way before Early Triassic.

However, there is scarce evidence for synchronous volcano-plutonic activity connected to subduction around that time. Intercalation of acidic tuff in the oceanic sequence alludes to the existence of arc-related volcanic activity (probably of the Kurosegawa Arc) during late Middle to early Late Permian. In addition, intercalation of andestic pyroclastics in the Late Triassic Kochigatani Group (SUYARI, 1960) can be applied as another evidence, although indirect, to support the development of an arc-trench system around end-Permian time. Although a radiometric age of 240Ma was reported from the Yatsushiro Igneous Rocks (an equivalent of the Terano Metamorphic Rocks) in Kumamoto Prefecture (NOHDA, 1973), it is regarded as the age of rejuvenation of K-Ar age of K-feldspar in 400Ma gneiss. It is suggested that most of the products of subduction-related volcano-plutonic activities, except small entities less than depictive size, had already been consumed through later subduction process or through later activities of large-scale strike-slip faults.

XI. Concluding Remarks: Two-phase Convergent History of the Northern Chichibu Basin in Late Paleozoic to Mesozoic Time

1. Distinction of Two Phases in Closing History of the Northern Chichibu Basin

From the beginning of 1980s, several sophisticated models have been proposed to explain the geotectonic evolution of the Late Paleozoic to Mesozoic Chichibu Terrane in terms of ancient plate interactions (e.g. KANMERA, 1980; ICHIKAWA, 1982; MARUYAMA & FURUTANI, 1983). Many of the proposers are in agreement that the kaleidoscopic rock assemblage of the northern subbelt of the Chichibu Belt was fundamentally manufactured through subduction-related tectono-sedimentary processes along the northern rim of the Northern Chichibu Basin during Jurassic Period.

Through the present study in Central Shikoku, new facts have been revealed mainly by virtue of microbiostratigraphical investigations. Among them, the most significant contribution is the discrimination of the two major tectono-stratigraphic units, i.e. the

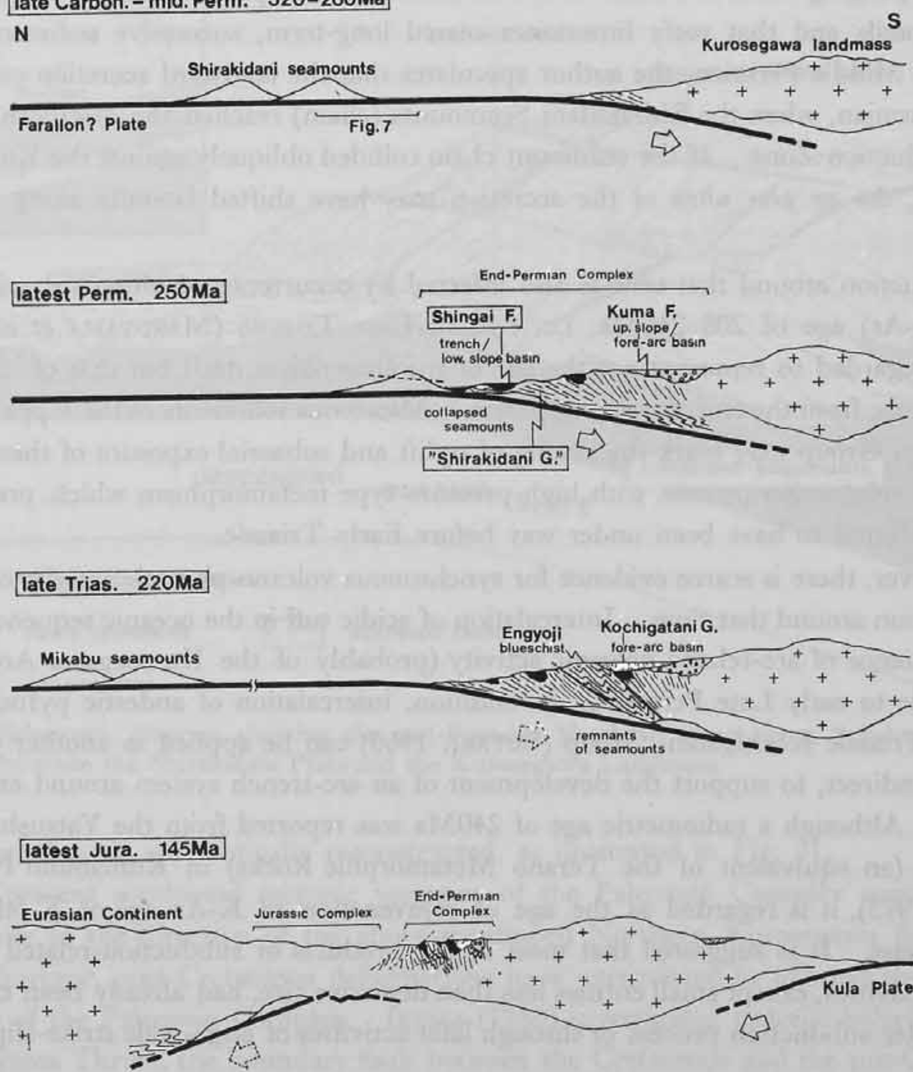


Fig. 32. Schematic model for two-phase closing history of the Northern Chichibu Basin in Late Paleozoic to Mesozoic time. After Isozaki (1986).

Paleozoic Complex and the Mesozoic Complex. In terms of landward mass accretion, these two units represent two intermittent tectonic events in the convergent history of the Northern Chichibu Basin. Namely, the Paleozoic Complex formed along the southern margin of the Northern Chichibu Basin in the end of Permian time, while the Mesozoic Complex was made during Jurassic time.

In this chapter, on the basis of the new data on the pre-Cretaceous rocks in Central Shikoku, the present author offers a two-phase subduction-accretion model to explain the Late Paleozoic to Mesozoic geotectonic evolution of the Northern Chichibu Basin. Fig. 32 schematically illustrates the two subduction-accretion phases in the closing history of the Northern Chichibu Basin from Carboniferous to Jurassic time. The end-Permian emplacement of the Paleozoic Complex along the Northern Kurosegawa Subduction Zone was already discussed in the preceding chapter. Concerning the Jurassic culmination of landward mass accretion that formed the Mesozoic Complex, brief remarks will be given in the next section.

2. Formation of the Mesozoic Complex and the Final Closure of the Northern Chichibu Basin

As described in Chapter V, the Mesozoic Complex consists of chaotically mixed rocks of various lithologies and ages. It is composed both of land-bound rocks and oceanic ones, as in the case of the Paleozoic Complex. Fossils from these rocks vary in age, ranging from Late Carboniferous to Middle Jurassic with the youngest of late Middle Jurassic age. Judging from the complicated association of huge bodies of the various kinds of rocks and their mode of occurrence, the Mesozoic Complex is regarded as landward accreted materials in convergent plate boundaries. As it is covered unconformably by the Lower Cretaceous rocks of shallow-water facies, the accretionary process of the Mesozoic Complex is regarded to have ceased prior to the Early Cretaceous transgression. From the viewpoint of paleomagnetism, SAKAI & MARUYAMA (1985) lately speculated on the rapid northward migration of the Kurosegawa Landmass in the latest Jurassic. This speculation fits in well with the above-mentioned landward mass accretion that culminated in Middle-Late Jurassic time in the Northern Chichibu Basin.

Information on Mesozoic plate convergence in the Northern Chichibu Basin has not been fully provided yet. Subduction may have occurred along 1) the northern margin, 2) the southern margin or 3) both of the margins of the Northern Chichibu Basin. ICHIKAWA (1982) suggested Early-Middle Jurassic accretion along the southern margin of the basin, on the basis of geological information in Kii Peninsula (ICHIKAWA *et al.*, 1981). Concerning the study area in Central Shikoku, informative data on the location and configuration of Jurassic plate convergence have been scarcely available.

Although details are unknown, Mesozoic ocean basins between the Hida Terrane (Sino-Korean Landmass) and the Kurosegawa Landmass, including Mino-Tamba Basin and the Northern Chichibu Basin, are generally regarded to have closed almost simultaneously around the end of Jurassic time (e.g. KANMERA, 1980). Under the circumstances, the present author tentatively treats the Mesozoic Complexes in the Northern Subbelt of the Chichibu Belt and the Mino-Tamba Belt together in Fig. 32 in order to discriminate them from the Paleozoic Complex formed in the far south. It is suggested that the Sanbagawa crystalline schists had formed in connection with the Jurassic plate convergence but remained deep-seated until its final uplift in Cretaceous time.

FAURE (1985) suggested that a superficial nappe containing reefy limestone, such as the Shirakidani limestone, were originally derived from certain place in the Inner Zone of Southwest Japan, where some large-scaled Permo-Carboniferous limestone plateaux develop. Furthermore, he supposed that this nappe had traveled for a long distance southward and had tectonically overlain upon the Sanbagawa Metamorphic Rocks and proper members of the northern subbelt as a huge allochthon. However, on the basis of the mutual linkage between the Kurosegawa Landmass and the Shirakidani Plate already in Permian time (Fig. 32), FAURE's speculation of Mesozoic transport of Permian limestones is safely denied.

3. Synthesis: Late Paleozoic to Mesozoic Evolution of the Northern Chichibu Basin

Concerning the pre-Cretaceous rocks in the northern subbelt of the Chichibu Belt, Central Shikoku, all of the above-mentioned geologic informations and discussion are summarized in the two-phased subduction-accretion model on the Late Paleozoic to Mesozoic evolution of the Northern Chichibu Basin as illustrated in Fig. 32. Especially, it is noteworthy that the Kurosegawa Landmass played an important role once in formation of the Paleozoic Complex in the end-Permian allochthonous stage, and again in formation of the Mesozoic Complex through its Late Jurassic collision against Asian continental margin.

This orthogonal subduction-collision tectonic model for the evolution of the Northern Chichibu Basin is quite inconsistent with the tectonic interpretation by TAIRA *et al.* (1981). They insist that large-scale strike-slip movement along major terrane boundaries is the most effective tectonic agent in building-up the edifice of the Japanese Islands, similar to the philosophy of Cordilleran suspect terranes (CONEY *et al.,* 1980). Although certain contribution by post-collisional strike-slip movements should be taken into account as secondary modification, it seems difficult to explain the well-documented in situ tectono-stratigraphic linkage between two geologic entities, for example that between the Kurosegawa Landmass and the Shirakidani Plate, in terms of strike-slip movements.

Following is a brief summary of the geotectonic evolution of the Northern Chichibu Basin from the Silurian to the Jurassic.

Siluro-Devonian: The Kurosegawa Landmass was located in a region far south of its present position and formed an active volcanic arc, delivering abundant felsic pyroclastics to its surroundings.

Late Early Carboniferous - Middle Permian: The Shirakidani Plate (the Farallon? or an unknown plate) on the north of the Kurosegawa Landmass subducted southward underneath the Kurosegawa Landmass. As the subduction proceeded, the Shirakidani Seamount chain gradually approached the Kurosegawa Landmass.

Late Permian - Early? Triassic: The subduction continued until the arrival of the Shirakidani seamount chain at the Northern Kurosegawa Subduction Zone in Late Permian, when landward mass accretion reached its culmination. The ocean basin south of the seamount chain was completely consumed in the Northern Kurosegawa Subduction Zone. The Shingai Formation and other formations of the Paleozoic Complex were sedimentarily and tectonically emplaced at this time.

Middle-Late Triassic: Despite the consumption of the oceanic plate of the Northern Chichibu Basin during this time, no conspicuous accretion took place in this duration. The Paleozoic Complex (already amalgamated to the Kurosegawa landmass) and crystalline schists were exposed to subaerial erosion level in Late Triassic.

Jurassic: The oceanic plate underlying the Mesozoic Northern Chichibu Basin was consumed between the Kurosegawa Landmass and the Asian Continent until their final collision. In Late Jurassic time, the Northern Chichibu Basin finally closed, leaving mutually juxtaposed Mesozoic and Paleozoic Complexes.

XII. Summary

1. The pre-Cretaceous rocks of the northern subbelt of the Chichibu Belt in Central Shikoku, Southwest Japan, consist of mutually distinct two tectonostratigraphic units: the Paleozoic Complex and the Mesozoic Complex (Fig. 2).

2. The Paleozoic Complex in the Yasuba-Shirakidani area, central Kochi Prefecture, comprises following five geologic units, i.e. the Gonyu Formation, the Shingai Formation, Unit I and Unit II of the "Shirakidani Group" and the Agekura Formation, from south to north (Fig. 3). The Kamiyakawa Formation, representing the Mesozoic Complex, is distributed on the north of the Paleozoic Complex. The Mesozoic Complex tectonically overlies the Paleozoic one along a remarkable fault newly named as the Agekura Thrust.

3. Constituent rocks of the Paleozoic Complex can be classified into two categories, namely land-bound rocks and oceanic ones. Rocks of the former type were primarily deposited or emplaced around the ancient Kurosegawa Landmass, while those of the latter type were formed in the midst of an ancient ocean.

4. Judging from sedimentary and structural features, the Shingai Formation was probably deposited in a "starved" trench or lower slope basins of the Northern Kurosegawa Subduction Zone.

5. On the basis of structural characteristics, tectonic slices of the "Shirakidani Group" are regarded as accretionary wedges formed through off-scraping and/or underplating in the Northern Kurosegawa Subduction Zone.

6. Permian conglomerate-bearing formations in the Outer Zone of Southwest Japan are classified into two types, namely Shingai-type and Kuma-type. Formations of the former type correspond to deposits in modern trench or lower slope basins, while those of the latter type are regarded as deposits in upper slope basins or fore-arc basins.

7. The Paleozoic Complex in the study area, as a whole, can be best understood as end-Permian subduction-related products in the Northern Kurosegawa Subduction Zone, which was quite remote from the "Asian Continent" at that time.

8. The closing history of the Northern Chichibu Basin in Late Paleozoic to Mesozoic time is marked by two major tectonic phases, i.e. one in the end of Permian and the other in the Jurassic, as summarized in Fig. 32. The Mesozoic Complex was formed between the Kurosegawa Landmass and the Asian continental margin (Sino-Korean Landmass), as the Northern Chichibu Basin closed by virtue of the northward migration and collision of the former landmass against the latter one around the end of Jurassic Period.

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