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Stratigraphy and geologic development of the Carboniferous to Permian strata in the Atetsu region, Akiyoshi Terrane, Southwest Japan

By

Takahito NAKA

with 4 tables, 44 Figures and 8 Plates

(Recieved November 18, 1994)

Abstract: Stratigraphies and developmental history of the Carboniferous to Permian strata of the Akiyoshi Terrane were reconstructed on the basis of detailed investigations of the radiolarian biostratigraphy and geologic structure from the view point of an accretional active margin setting.

The Akiyoshi Terrane is characterized by major two different facies; carbonate, and siliceous and terrigenous rock facies. The carbonate rocks in the Atetsu region are represented by a reef complex, the Atetsu Limestone. The siliceous and terrigenous rocks are grouped into three facies types; the Terauchi, Fuyori, and Taniai Types, due to their stratigraphic and structural characteristics. The Terauchi Type is characterized by a coherent sequence, encloses remarkable amount of limestone clasts, and conformably overlies the Atetsu Limestone. This Type is trench-fill sediments covering directly the colliding seamount. The Fuyori Type is composed of the lower chert, the middle siliceous mudstone, and the upper coarser clastic rocks. The Fuyori Type is corresponds to the oceanic plate stratigraphy indicating the landward migration of the depositional site. The Taniai Type is a melange suite containing various-sized exotic blocks of different lithologies.

Investigations of geologic structures, especially recognition of the nappe boundary bending folds, indicates that the Carboniferous to Permian rocks in the Atetsu region formed the major two nappes that were probably formed by the collision of seamount.

The biostratigraphic study concentrates to the correlation between radiolarian and fusulinid assemblages. The first occurrence of *F.* sp. cf. *F. japonicus* (radiolaria) is correlated to the base of *Lepidolina imamurai* Zone (fusulinacean zone), and indicates the Middle / Late Permian boundary.

The age of the lower limit of the Terauchi Type sediments indicates the arrival time of the seamounts to a trench. The seamount capped by the Atetsu Limestone collided during the *F.* sp. cf. *F. japonicus* Zone (Late Permian). The arrival times of several seamounts in the Akiyoshi Terrane are nearly same among the different regions. This indicates that the seamounts in the Akiyoshi Terrane were arranged nearly parallel to the trench.

CONTENTS

I. Introduction

The Japanese Islands mainly consist of the late Paleozoic to Cenozoic accretionary complexes, formed at an ancient subduction zone in an arc (continent) - trench system.

The pre-Tertiary rocks in Southwest Japan are exposed between the Japan Sea side (north) to the Pacific side (south), and they generally become younger to the south. There have been divided into several geologic units as nappes that are called as Terranes, Belts and Zones (Ichikawa, 1984, 1990; Watanabe *et al.*, 1987; Isozaki and Maruyama, 1991; etc.). The structural relationships between units, their approximate age of accretion to continent (arc), the depositional setting of several lithological groups of accretionary complexes, have been studied in detail. However, it is not yet clear about the exact time of the collision of sea mounts and other associated events, and about the process and environment of both oceanic and terrigenous deposits, in different areas of different terranes on the basis of concretely evidences. Especially, the origin and emplacement process of oceanic rocks, typified by reefal limestones, which are more or less included in the accretionary complexes, and structural relationship between oceanic rocks and terrigenous clastic rocks are great problems and interests for geologists who work on the tectonic evolution of accretionary complexes.

The main purpose of the paper is clarification of the stratigraphical and structural characteristics of the accretionary complex affected by collision of large scale oceanic rocks. Detailed study was carried out by the author in the Atetsu and adjacent regions of the Akiyoshi Terrane (Ichikawa, 1984). The stratigraphy of the latest Permian accretionary complex at the Akiyoshi Terrane has been repeatedly studied, however, the present investigation expresses further more details in lithostratigraphy, radiolarian biostratigraphy, and geologic structure of the Carboniferous to Permian sedimentaries. The paper discusses (1) correlation between the radiolarian and fusulinacean biostratigraphies, (2) sedimentary and structural characteristics of oceanic and terrigenous rock units related to the large scale collision of oceanic materials, (3) the structural relationship between oceanic reef complexes (basaltic rocks and limestones) with the surrounding and covering clastic sediments (including cherts, mudstones, and sandstones), and (4) the geologic developments of the Akiyoshi Terrane.

II. Tectono-stratigraphic division of the Inner Zone of Southwest Japan

The geotectonic map of the Inner Zone of Southwest Japan, marking its southern boundary by the Median Tectonic Line, is based on the date of several works (Fig. 1). The Inner Zone is composed of following terranes / belts from north to south with tectonically downward, (1): Oki-Hida Terranes (a part of the Yangtze and/or the North China Craton), (2): Sangun-Renge Belt (high P/T metamorphic group around 300Ma in radiometric age), (3): Akiyoshi, Maizuru and Ultra-Tamba Terranes (the latest Permian accretionary complexes), the theme of the paper, (4): Suo and Chizu Terranes (high P/T metamorphic rocks around 220 Ma and 180 Ma in radiometric ages, respectively), (5): Mino and Tamba Terranes (the Jurassic accretionary complexes of which the high T/P metamorphosed facies and granites are referred to the Ryoke Terrane). These terranes form a pile of nappes, in which the older nappe structurally overlies the younger nappe (e.g. Hayasaka, 1987).

This chapter deals with the reviews of the latest Permian accretionary complexes (3) and high P/T metamorphic rocks terranes (2 and 4).

A. Akiyoshi Terrane

The Akiyoshi Terrane (Ichikawa, 1984) the latest Permian accretionary complex, is tectonically underlain by the Suo and the Maizuru Terranes, and overlain by the Sangun-Renge Belt. The contacts between the Akiyoshi Terrane and the underlying and overlying terranes are originally low-angle faults (thrusts), and a pile nappe structure is formed (e.g. Hayasaka, 1987; Sugimoto *et al.*, 1990; Kabashima *et al.*, 1993).

The Akiyoshi Terrane is composed of the weakly metamorphosed and intensely deformed Carboniferous to Permian sedimentary rocks. The rocks are grouped three fault-bounded lithologic units by Sano and Kanmera (1988) and Kanmera and Sano (1991) as follows: carbonate rocks (greenstone, limestone, spicular chert), siliceous rocks (greenstone, chert, terrigenous rocks) and terrigenous clastic rocks (mudstone, olistostromes, etc.). The Upper Paleozoic rocks of the Akiyoshi Terrane are unconformably overlain by the Upper Triassic and Lower Jurassic non-marine and shallow marine sediments.

The Akiyoshi Terrane is characterized by several large masses of sea mount fragments, limestones and basic volcanic rocks. The important representative of which are refereed to from west to east, the Hirao, Akiyoshi, Taishaku, Oga, Atetsu, and Omi Limestones (Fig. 1). In

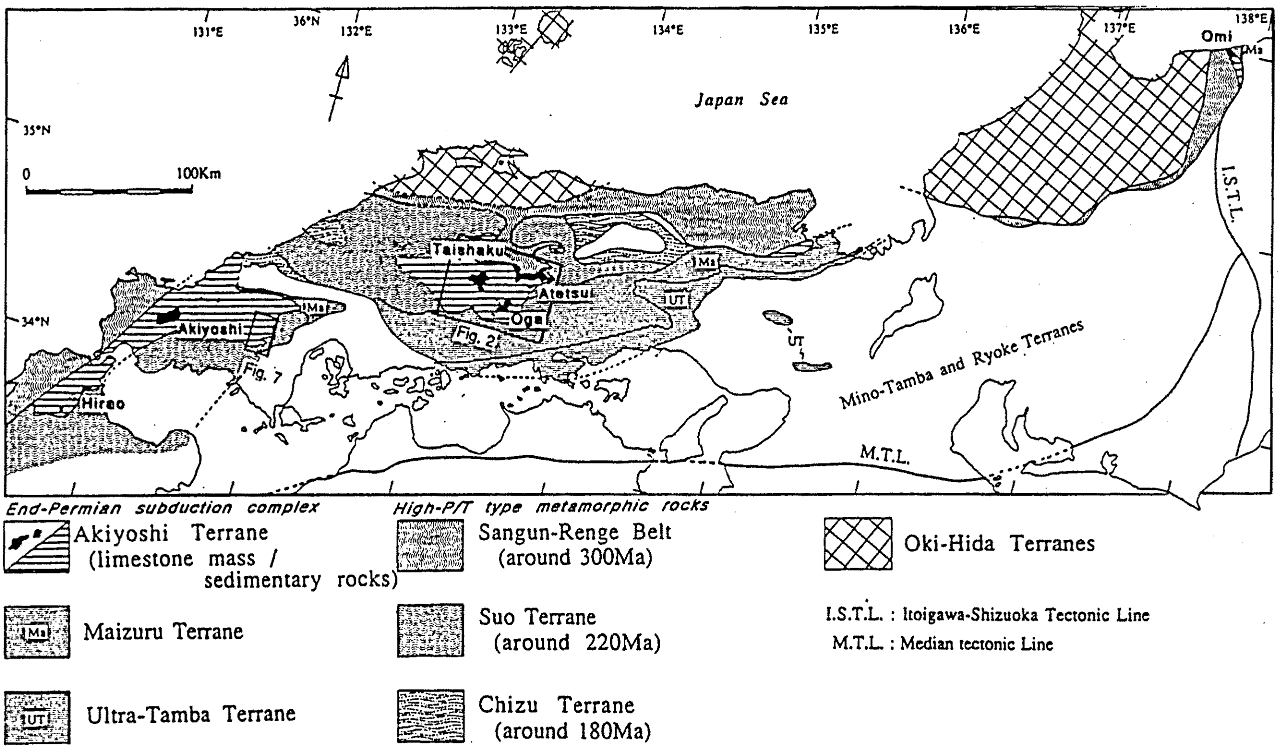


Fig. 1 : The Pre-Cretaceous tectno-stratigraphic division of the Inner Zone of Southwest Japan. Compiled from Isozaki and Maruyama (1991), Sugimoto *et al.*, (1990), and Komatsu (1990). The areas of Figs. 2 and 7 are shown.

other latest Permian accretionary complexes, such as the Maizuru and Ultra-Tamba Terranes, no large mass of limestone is found. The nature of sediments and fossils assemblages of the limestones are similar except those found in the crystalline Hirao Limestone (e.g. Hase, 1984).

Important publications concerning this terrane are listed below.

1. Biostratigraphical, sedimentological and geochemical studies in carbonate rocks (Ozawa, 1923; Sada, 1965; Okimura, 1966; Ota, 1968; Hase *et al.*, 1974; Hase and Nishimura, 1979; Tazaki *et al.*, 1989; etc.)
2. Radiolarian biostratigraphical studies in siliceous rocks (Naka *et al.*, 1986; Goto, 1988; Uchiyama *et al.*, 1986; Sano *et al.*, 1987; etc.)
3. Studies on depositional setting of three lithologic units based on different parameters (Sano and Kanmera, 1988; Kanmera and Sano, 1991)
4. Studies on pile nappe structure within the terrane (Okimura *et al.*, 1981; Goto, 1988; Otoh, 1987; Naka and Sakamoto, 1990; Sakamoto *et al.*, 1990)
5. Studies on accretion mechanism of an ancient seamount associated with oceanic sediments of the Akiyoshi reef complex (Sano and Kanmera, 1991a, b, c, d).

B. Maizuru Terrane

The Maizuru Terrane occupies the structural position between the overlaying Akiyoshi and underlying Ultra-Tamba Terranes. The Terrane shows a distinct zonal arrangement generally extending in ENE-WSW direction, and is separated by thrusts (Fig. 1).

The Maizuru Terrane (or Maizuru Belt, Matsushita, 1950; Hayasaka, 1990) comprises of the Permian clastic rocks (Maizuru Group), Yakuno ophiolite and its related rocks, unconformably overlain by the Early and Late Triassic shelf facies sediments. This Terrane is distinguished from other terranes by the presence of the Yakuno Ophiolite and related rocks. Furthermore, the Permian succession also differs from that of the Akiyoshi Terrane by the remarkable absence of chert and presence of the unconformably overlain Lower Triassic strata.

C. Ultra-Tamba Terrane

The Ultra-Tamba Terrane (Caridroit *et al.* 1985; Ishiga, 1986a) is tectonically underlain by the Jurassic accretionary complex (Tamba Terrane) and is overlain by the Maizuru Terrane. This terrane is distinct in its tectonical position, strong deformation, and characteristic radiolarian fauna.

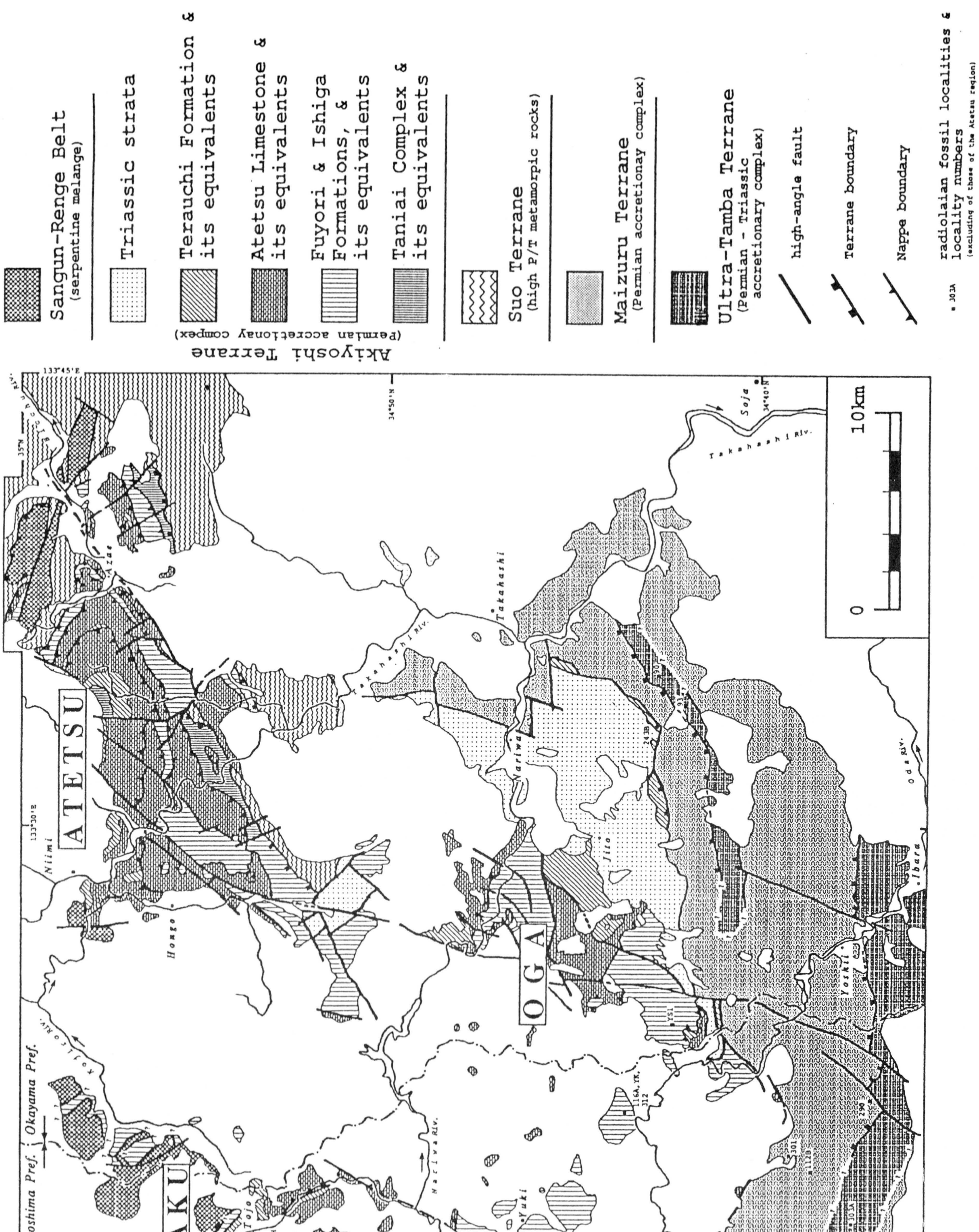
The Terrane is composed of three tectonic units, the UT1 (mainly Permian sandstone), UT2 (Permian chert, shale and sandstone), and UT3 (Upper Carboniferous to Permian basic volcanic rocks, chert and shale), in tectonically ascending order (Ishiga, 1990a).

D. Sangun-Renge Belt, Suo and Chizu Terranes

(high-P/T metamorphic rocks)

High P/T metamorphic rocks in the Chugoku district have been subdivided into the Sangun-Renge Belt (radiometric concordant age around 300Ma), Suo Terrane (radiometric concordant age around 220Ma), and Chizu Terrane (radiometric concordant age around 180Ma) (Nishimura, 1990; Fig. 1).

The Sangun-Renge Belt consists of a serpentine melange including metagabbroic rocks, schists and


Sangun-Renge Belt
(serpentine melange)
Triassic strata
Terauchi Formation & its equivalents
Atetsu Limestone & its equivalents
Fuyori & Ishiga Formations, & its equivalents
Taniai Complex & its equivalents
Akiyoshi Terrane
(Permian accretionay compex)
Suo Terrane
(high P/T metamorpic rocks)
Maizuru Terrane
(Permian accretionay complex)
Ultra-Tamba Terrane
(Permian - Triassic accretionary complex)
high-angle fault
Terrane boundary
Nappe boundary
radiolaian fossil localities & locality numbers
ATETSU
OGA
TAISHAKU
Niimi
Takahashi
Hiroshima Pref.
Okayama Pref.
Ibara
Miwa
Yoshii
Jito
Soja
Saijo
10km
0

ultramafic rocks. The rocks of this belt extend from the northern Kyushu to Hida district (Nishimura, 1990).

The Suo Terrane is widely distributed in the western Chugoku district, and is composed of pelitic, psammitic and basic schists. It is compositionally in the association with the Akiyoshi Terrane, and was inferred to have been the metamorphosed latest Permian accretionary complexes (Hayasaka, 1987).

The Chizu Terrane is developed in the northern central Chugoku district, and consists of pelitic, psammitic, basic schists, and remarkable siliceous schists. It is considered to be the metamorphosed Jurassic accretionary complex of the Tamba Terrane (Hayasaka, 1987; Nishimura, 1990).

III. Outline of geology

A. Atetsu region

The Atetsu region, encompasses Niimi City, Takahashi City, and Hokubou Town, lying in the northwestern Okayama Prefecture (Figs. 2 and 3). The carbonate rock facies of the Carboniferous to Permian Atetsu Limestone, the three groups of major siliceous and terrigenous clastic rocks, and two groups of high-P/T metamorphic rocks are developed in this region (Fig. 3). The carbonate, siliceous; and terrigenous rocks are the representatives of the Akiyoshi Terrane. The Triassic sediments are often sporadically exposed

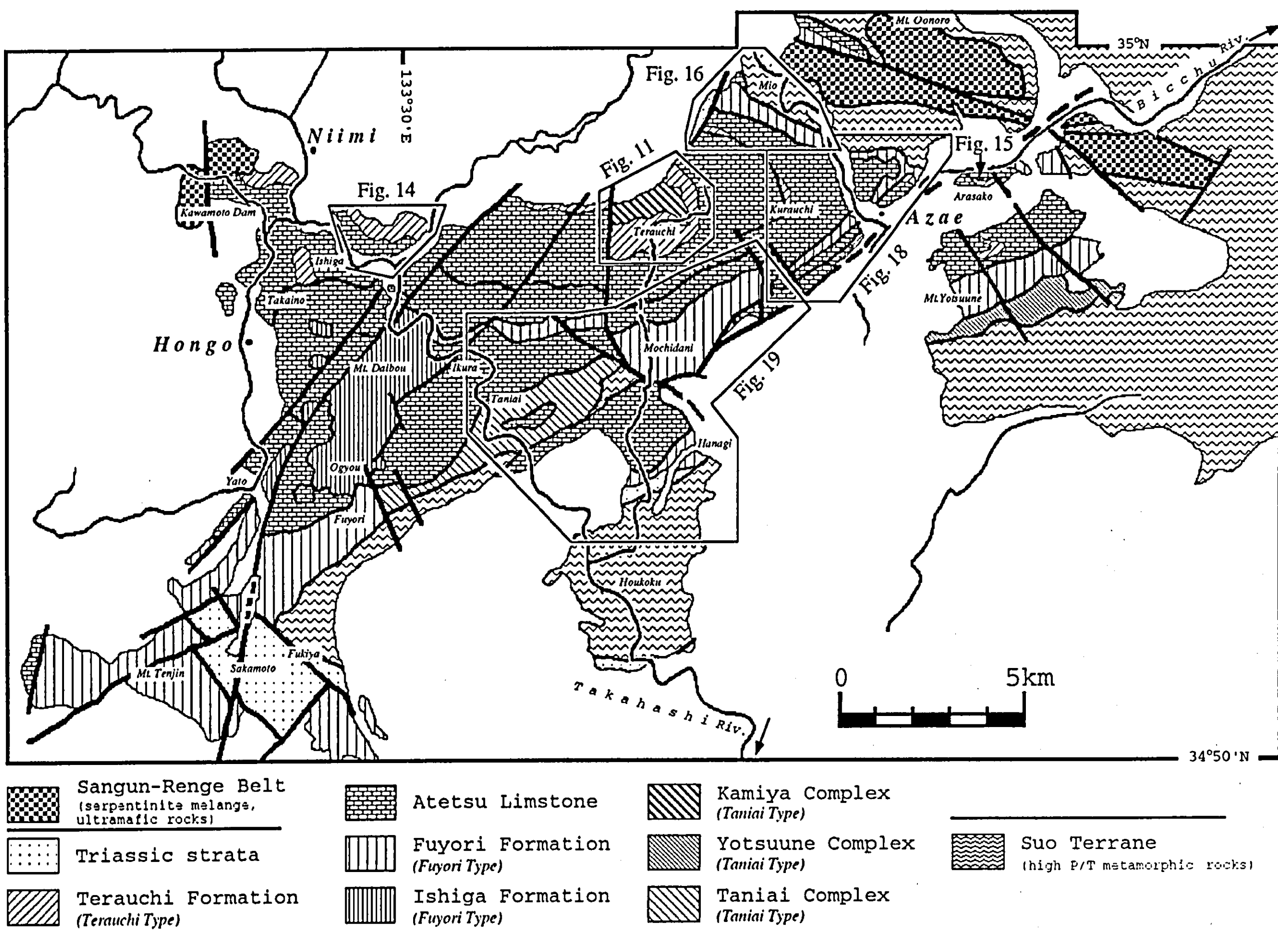


Fig. 3 : A simplified geologic map of the Atetsu region and showing areas of detailed geological maps (Figs. 11, 14, 15, 16, 18 and 19). Compiled from Okayama Prefectural Office (1979), Sada (1965), Tanabe (1973MS), Yoshida (1980MS), Okimura *et al.* (1981), Nishidani (1985MS), Takeda and Nishimura (1989), Sugimoto *et al.* (1990) Sakamoto (1991MS), and this study.

←

Fig. 2 : The pre-Cretaceous compiled geologic map of the Atetsu, Taishaku and Oga regions and showing radiolarian fossil localities excluding those of the Atetsu region. The location of the map is shown in Fig. 1.

Date sources are listed below :

All mapped area; Okayama Prefectural Office (1979), Hiroshima Prefectural Office (1964)

Atetsu region; Sada (1965), Ministry of International Trade and Industry (1967, 1968, 1969, 1980), Tanabe (1971MS, 1973MS), Yoshida (1980MS), Okimura *et al.*, (1981), Nishidani (1983MS, 1985MS), Otoh (1987), Sugimoto *et al.* (1990), Sakamoto (1991MS), this study

Oga and Yoshii regions; Yoshimura (1961), Hase *et al.* (1975), Yokoyama *et al.* (1979), Yokoyama (1980), Otoh (1985), Ishiga *et al* . (1988, 1989), Suzuki *et al.* (1990), Tsutsumi (1991), Sugata *et al.* (1992)

Taishaku region; Hase *et al.* (1974), Oho *et al.* (1985), Oho and Sada (1986), Goto (1988)

Previous works: The Atetsu region has been one of the center of geological study in the Akiyoshi Terrane because of stratigraphic and paleontological interests of the Late Paleozoic. The geological map published by Sato (1938) for the region and the stratigraphy described by Motizuki (1938) served the basis for future investigations. Kobayashi (1950) summarized the knowledge of geology in
the region. Okimura (1958, 1963, 1966) investigated the biostratigraphy of smaller foraminifera of Carboniferous strata and developed an improved biostratigraphy of the lower half of the Atetsu Limestone. Fusulinacean zones of the Atetsu Limestone were further added by Imamura (1959), Sada (1960, 1961a, 1961b, 1964, 1965), and Nogami (1962). The other important paleontological contributions are Koike (1967) for Carboniferous conodont zonation of the Atetsu Limestone, and Yamashita and Ishiga (1990) for correlation of the radiolarian and fusulinacean zonation scheme. The geology of the region is also described by Yoshimura *et al.* (1959), Yoshimura (1961), Kawada *et al.* (1960); Kawada and Takeshi (1960), Kawada (1963) and Ministry of International Trade and Industry (1967, 1968, 1969). The depositional environment of the limestone conglomerates was discussed by Sakagami and Miyama (1988). While describing the geological structure of the Atetsu region, Okimura *et al.* (1981) brought out the nappe structure in the region. Geologic development of the region was discussed by Otoh (1987), Takeda and Nishimura (1989), and Sugimoto *et al.* (1990).

A comparative scheme of the stratigraphy of previous workers with this work in the Atetsu region is given in Tables 1, 2, 3 and 4 in Chapter IV.

The unpublished works by the students of the Hiroshima University are also necessary to be noted. They were submitted as theses for graduate and postgraduate (Master) course of the Institute of Geology and Mineralogy, Faculty of Science, Hiroshima University. They are Tanabe (1971MS, 1973MS), Yoshida (1980MS), Akamatsu (1980MS), Nishidani (1983MS, 1985MS), Sakamoto (1989MS, 1991MS).

1. Atetsu Limestone

The Early Carboniferous to Middle (and partly Late) Permian Atetsu Limestone is widely distributed in the region covering an area approximately 20 x 6 square kilometers (Fig. 3) and is composed of basaltic lava and tuff at the base, succeeded by limestones intercalated with spicular chert, and is covered by the late Middle to early Late Permian clastic rocks (Terauchi Formation; Fig. 5). Based on lithologic characteristics of the limestones and the underlying basic volcanics, two facies, Southern and Northern Facies, had already been recognized by Tanabe (1973MS) and Okimura *et al.* (1981) (Figs. 5 and 22).

2. Siliceous and terrigenous clastic rocks

Carboniferous to Permian siliceous and terrigenous clastic rocks in the Atetsu region are divided into six rock units; the Terauchi Formation (redefined), Fuyori Formation (redefined), Ishiga Formation, Taniai Complex, Kamiya Complex (newly proposed), and Yotsuune Complex. The lithological and tectonical studies of six rock units in the Atetsu region suggest the division into three lithostratigraphical and structural types, namely the Terauchi, Fuyori and Taniai Types (Figs. 4, 5 and 6). This new division is important to clarify the tectonic evolution of the Akiyoshi Terrane as an accretionary complex.

a. Terauchi Type : The Terauchi Type is characterized by a coherent sequence overlying the Atetsu Limestone, and represents the Terauchi Formation. Further subdivisions are here proposed based on lithostratigraphic position and lithological characters, as Northern and Southern Facies (Fig. 5). Here, in the text the Northern Facies of the Terauchi Formation will be often referred as "Northern" Terauchi Formation and the Southern Facies as "Southern" Terauchi Formation. The "Northern" Terauchi Formation lies above the Northern Facies of the Atetsu Limestone and the "Southern" above the Southern Facies of the Limestone.

b. Fuyori Type : The Fuyori Type is characterized by fault-bounded units which although show a representative succession of chert in the lower part, siliceous mudstone and mudstone in the middle, and the upper part including sandstone and alternations of sandstone and mudstone (Fig. 6). The Fuyori Formation is this type. The Ishiga Formation is possibly this type.

c. Taniai Type : The Taniai Type is represented by a melange suite with exotic blocks of various sized of chert, limestone, basic volcanics, etc. embedded in mudstone matrix (Fig. 6). The Taniai Complex , Kamiya Complex, and the Yotsuune Complex are included in this type. Their original sequences of the composed rocks are obscure. Therefore, the term of Complex, which is followed as International stratigraphic guide edited by Hedberg (1976), is used instead of Formation.

3. Triassic Strata

The Triassic strata in the Atetsu region consist of sandstone and mudstone with some coal seams, and are up to 100 meters thick. They have been correlated with the Upper Triassic Nariwa Group which is widely distributed in the Oga region (see Fig. 2). The Triassic strata in Atetsu are distributed in a narrow belt with scattered outcrops as exposed in Hanagi, Yotsuune, Ikura, Mio and Fukiya areas (Fig. 3).

4. High-P/T metamorphic rocks

The high-P/T metamorphic grade of rocks are widely distributed in the southern, northeastern and northwestern end of the Atetsu region. The metamorphic rocks are divided into two assemblages, pelitic and basic schists assemblage and the serpentine melange assemblage including blocks of metagabbroic rocks and schists. Nishimura and Shibata (1989) and Nishimura (1990) considered them as constituents of the Chizu Terrane. Sugimoto *et al.* (1990) however, found that the rocks of the Sangun-Renge Belt (the latter assemblage) are confined in the Kawamoto Dam and Mt. Oonoro areas, and thrust over the Atetsu Limestone, as well as over the former metamorphic assemblage (Figs. 2 and 3). The "metagabbro" by the Okayama Prefectural Office (1979) in the northeastern Atetsu region is also included in the Sangun-Renge Belt (Fig. 3). Sugimoto *et al.* (1990) and Hayasaka (1992) have also suggested that the pelitic and basic schists in and around the Atetsu region seem to continue to the Suo Terrane.

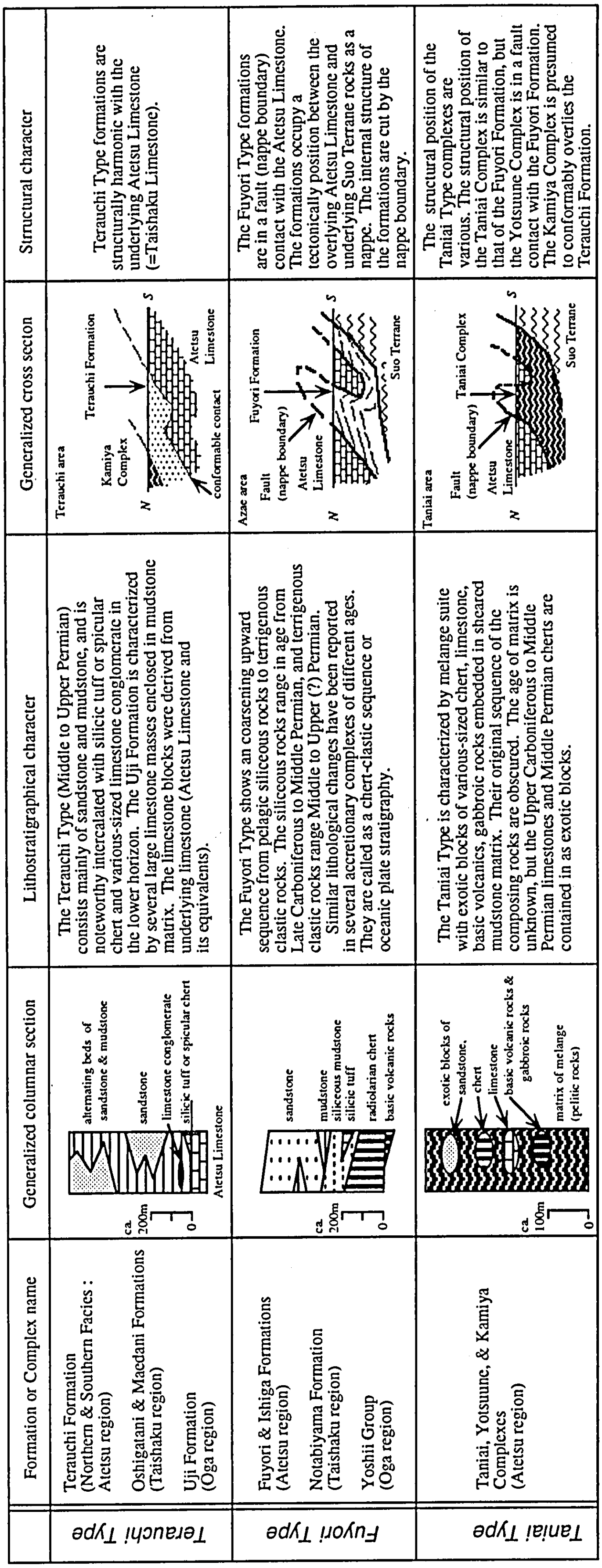


Fig. 4 : A diagram showing lithostratigraphical and structural characteristics of the three major types of rock units of the Akiyoshi Terrane. Simplified stratigraphy and nappe structure of the Akiyoshi Terrane in the Atetsu region are also shown.

180Ma) of the schists of the Atetsu region which were probably affected in the thermal contact metamorphism by granites of the Cretaceous age. Therefore, it is preferred to use the Suo Terrane in the sense of Sugimoto *et al.* (1990) and Hayasaka (1992). The Suo Terrane tectonically underlies the Akiyoshi Terrane.

5. Kanmon Group

The Lower Cretaceous Kanmon Group is well developed in the western part of the Chugoku district, it is however scattered in small outcrops in the Atetsu region. It is mainly composed of red shale, silicic to intermediate tuffs and tuff breccias including limestone clasts. They are associated with non-marine siltstone and mudstone. The Kanmon Group unconformably overlies the older strata.

6. Silicic volcanic formations (collectively grouped as rhyolite in several geologic maps; Figs. 11, 14, 16, and 18)

Upper Cretaceous silicic volcanics are also largely developed in the Chugoku district as well as the Atetsu region. They mainly consist of rhyolitic lava and tuff breccia with small amount of non-marine sedimentary rocks. In the region, the volcanics unconformably overlies the sedimentaries, but in some cases they have intruded the sedimentaries as a large number dikes of porphyry. The age of the dikes is still not settled and may be around the Late Cretaceous.

7. Bihoku Group

The Bihoku Group of the Miocene is found in small isolated outcrops in the central Chugoku district. In the Atetsu region, it concentrates in the Azae area (Figs. 16 and 18). The Group is composed of sandstone, mudstone, and conglomerate, and contains invertebrate fossil, such as bivalves and gastropods.

B. Taishaku and Oga regions

Compiled columnar sections of the Taishaku and Oga regions, and simplified geologic map of the regions are shown in Figs. 2, 5 and 6. In the Taishaku region, the Notabiyama Formation, Taishaku Limestone Group, Oshigatani Formation and Maedani Formation are developed (Hase *et al.*, 1974; Goto, 1988). In the Oga region, the Yoshii Group, Koyama Limestone, Nakamura Limestone, Sugeno Chert Formation and Uji Formation can be distinguished by Sano *et al.* (1987), Yokoyama *et al.* (1979) and Yokoyama (1980).

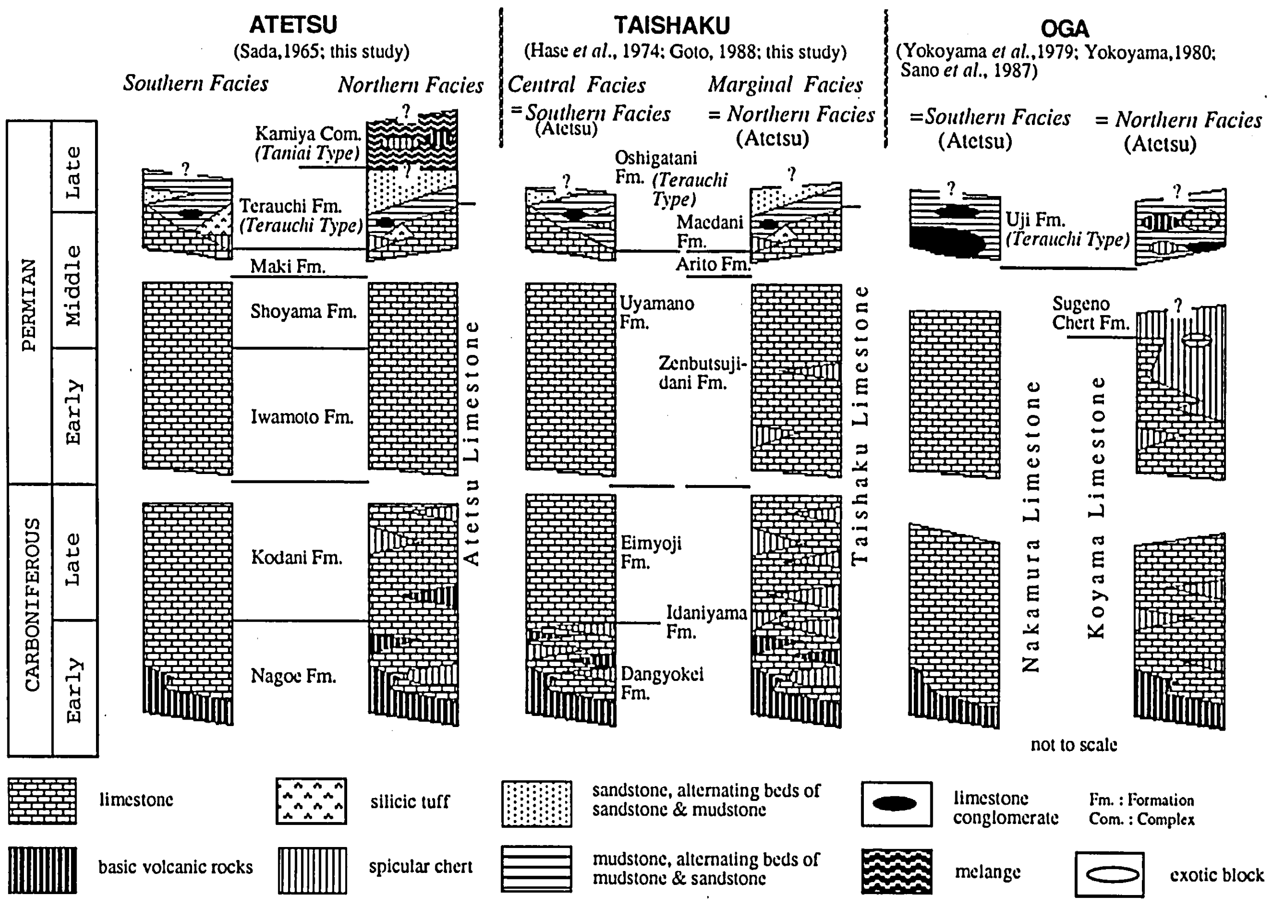


Fig. 5 : Generalized stratigraphic columns of the carbonated rocks and their covered terrigenous clastic rocks in the Atetsu, Taishaku and Oga regions.

Sugeno Chert Formation and Uji Formation can be distinguished by Sano *et al.* (1987), Yokoyama *et al.* (1979) and Yokoyama (1980).

The Yoshii Group (Yoshimura, 1961; redefined by Sano *et al.*, 1987) in the Oga region comprises of chert, siliceous mudstone with silicic tuff, and mudstone and sandstone in ascending order. The Notabiyama Formation (Yokoyama, 1957; Hase *et al.*, 1974; redefined by Goto, 1988) in the northern Taishaku region has a similar lithostratigraphy of that of the Yoshii Group although it lacks sandstone. The Yoshii Group and its equivalents extend to WNW but crops sporadically and is concealed at places under the Cretaceous volcanics, through the Yuki area, to the southern Taishaku region (Fig. 2). Rich radiolarian and conodont assemblages have been recovered from all the lithological units except for sandstone (Oho *et al.*, 1985; Sada *et al.*, 1985; Sano *et al.*, 1987; Goto, 1988; this study).

The Koyama Limestone (Yoshimura, 1961; Yokoyama *et al.*, 1979; redefined by Sano *et al.*, 1987 as Group) and Nakamura Limestone (Yoshimura, 1961; Yokoyama, 1980) in the Oga region are composed of basic volcanic rocks in the lower part and limestone with spicular chert in the upper part. The Taishaku Limestone (Hase *et al.*, 1974 as Group) in the Taishaku region also consists of basic volcanic rocks and limestones, and Central and Marginal Facies had been recognized based on lithologic characteristic of limestones (Hase *et al.*, 1974).

The Sugeno Chert Formation (Sano *et al.*, 1987) is mainly composed of spicular chert with displaced limestone.

The Uji Formation in the Oga region (Yoshimura, 1961; Sano *et al.*, 1987) consists of chaotic mudstone including limestone, chert and basic volcanics clasts of various sizes. The Oshigatani and Maedani Formations are distributed in the Taishaku region (Yokoyama, 1957; Hase *et al.*, 1974), and the former is mainly composed of mudstone and conglomerate, while the latter is dominantly sandstone. The two formations conformably overlie the Central and Marginal Facies of the Taishaku Limestone Group (Hase *et al.*, 1974).

The Upper Triassic Nariwa Group developed as a shelf facies and lies unconformably over the Upper Paleozoic of the Akiyoshi Terrane in the central Oga region (Otoh, 1985).

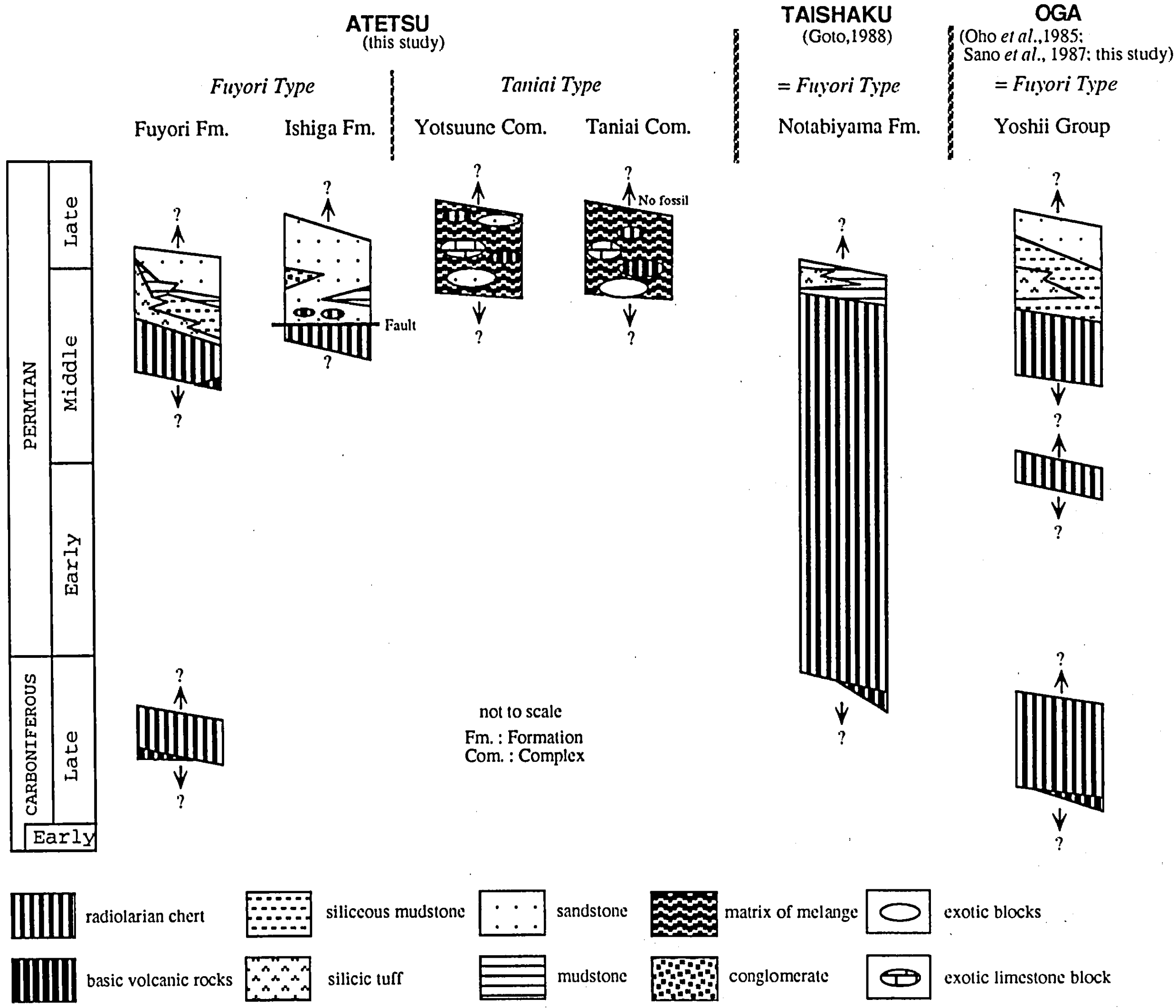


Fig. 6 : Generalized stratigraphic columns of the siliceous and terrigenous clastic rocks in the Atetsu, Taishaku and Oga regions.

C. Northwestern Yamaguchi and southeastern Shimane Prefectures

The formations of the Akiyoshi Terrane represented by the Permian Nishiki Group (Nishimura and Nureki, 1966; Naka *et al.*, 1986) and Suo Terrane rocks are widely exposed in the region (Fig. 7). The most representative feature of the region is the lack of large limestone masses which are commonly found in other regions of the Akiyoshi Terrane.

The Permian Nishiki Group mainly consists of sandstone, mudstone, and silicic tuff and contains less amount of chert, limestone, basic volcanics, and conglomerate. The group in Muikaichi area, the southeastern Shimane Prefecture, can be divided into three; chert (120 meters in thickness), mudstone with silicic tuff (200 meters in thickness), and sandstone (500 to 1000 meters in thickness), in ascending order (Naka *et al.*, 1986; Fig. 8). The Nishiki Group in Nishiki area is divided into three formations, the Lower (alternating beds of sandstone and mudstone, and alternating beds of mudstone and silicic tuff; 500 meters in thickness), Middle (silicic tuff; 150 to 200 meters in thickness), and Upper (sandstone and conglomerate, 500 to 1000 meters in thickness) Formations (Naka, 1987MS). The abundant and well-preserved Permian radiolarians are found in this group (Naka and Ishiga, 1985; Naka, 1987MS; Higashimoto *et al.*, 1986; Nishimura *et al.*, 1989), especially, the five Middle Permian radiolarian assemblage zones have been first recognized in the sequence from chert through mudstone to sandstone. They were found not only in the Akiyoshi Terrane but also in other latest Permian accretionary complexes (Ishiga *et al.*, 1986).

The Tsuno Group of Suo Terrane, is composed of pelitic, psammitic and basic schists (Nishimura and Nureki, 1966; Nishimura, 1971). The Tsuno Group in Nishiki area has been studied extensively among the formations of the Suo Terrane. The Tsuno Group, according to Nishimura *et al.* (1989), is the metamorphosed Middle Triassic sediments accumulated around trench and later undergone a single episode of glaucophanitic metamorphism.

The Tsuno Groups tectonically underlies the Nishiki Group across the Kitayama Fault (Nishimura *et al.*, 1989; Hirayama, 1992).

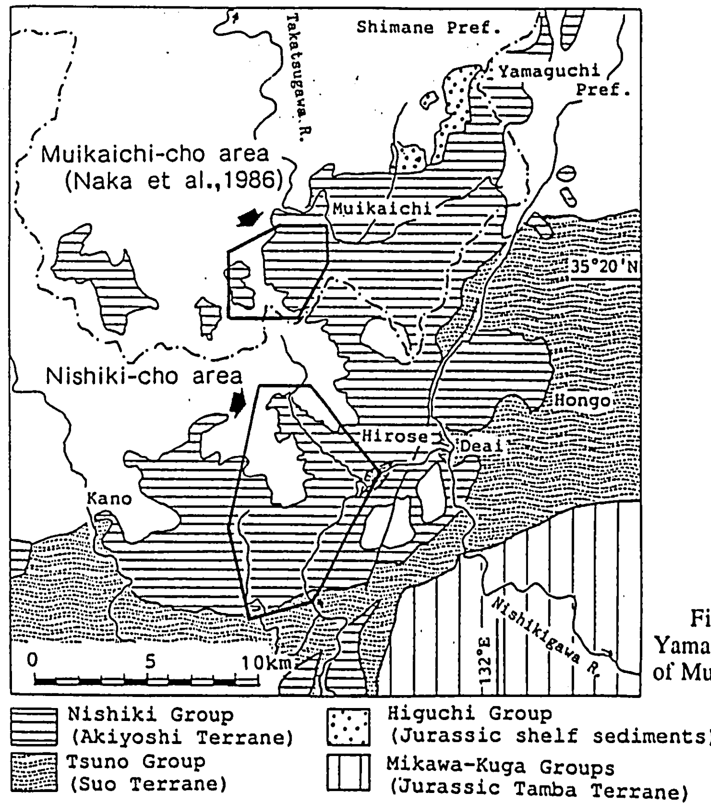


Fig. 7 : A simplified geologic map in the northeastern Yamaguchi and southwestern Shimane Prefectures showing areas of Muikaichi and Nishiki. Mapped area is shown in Fig. 1.

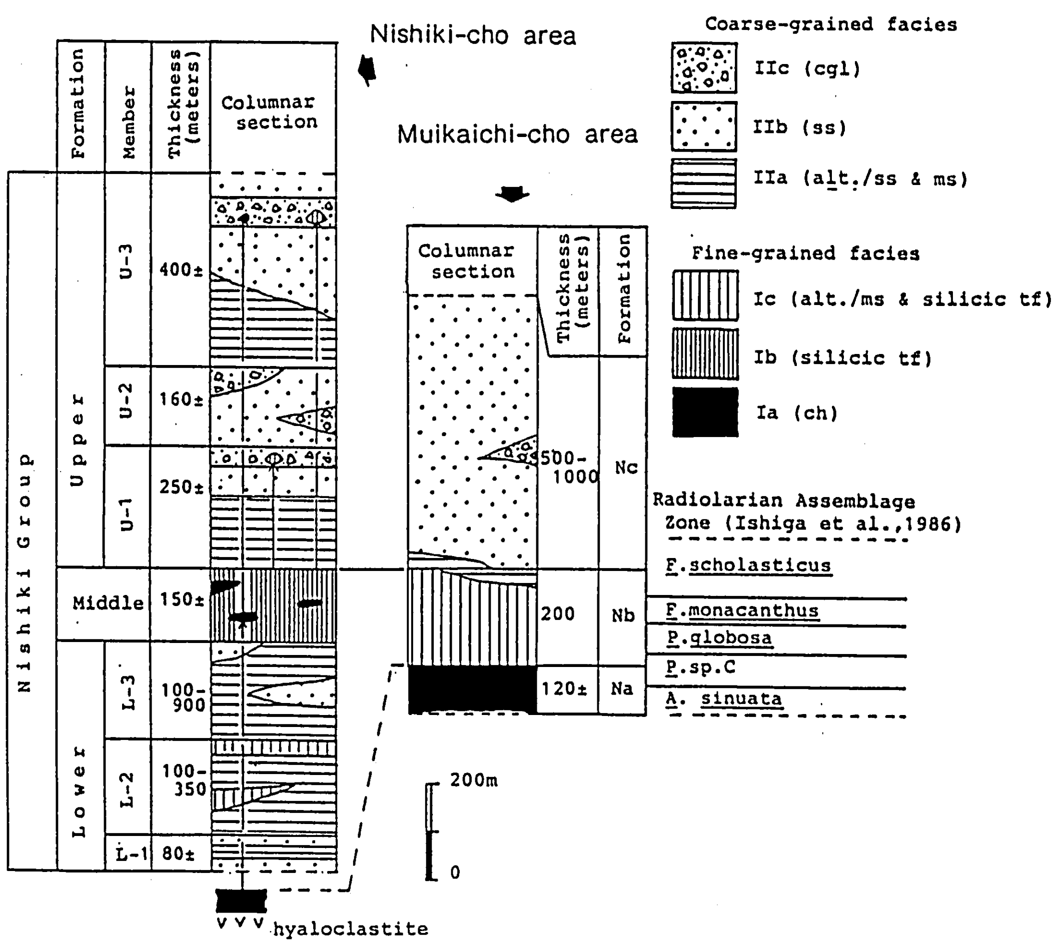


Fig. 8 : Generalized columnar sections of the Nishiki Group in the Nishiki and Muikaichi areas (modified from Naka, 1987MS).

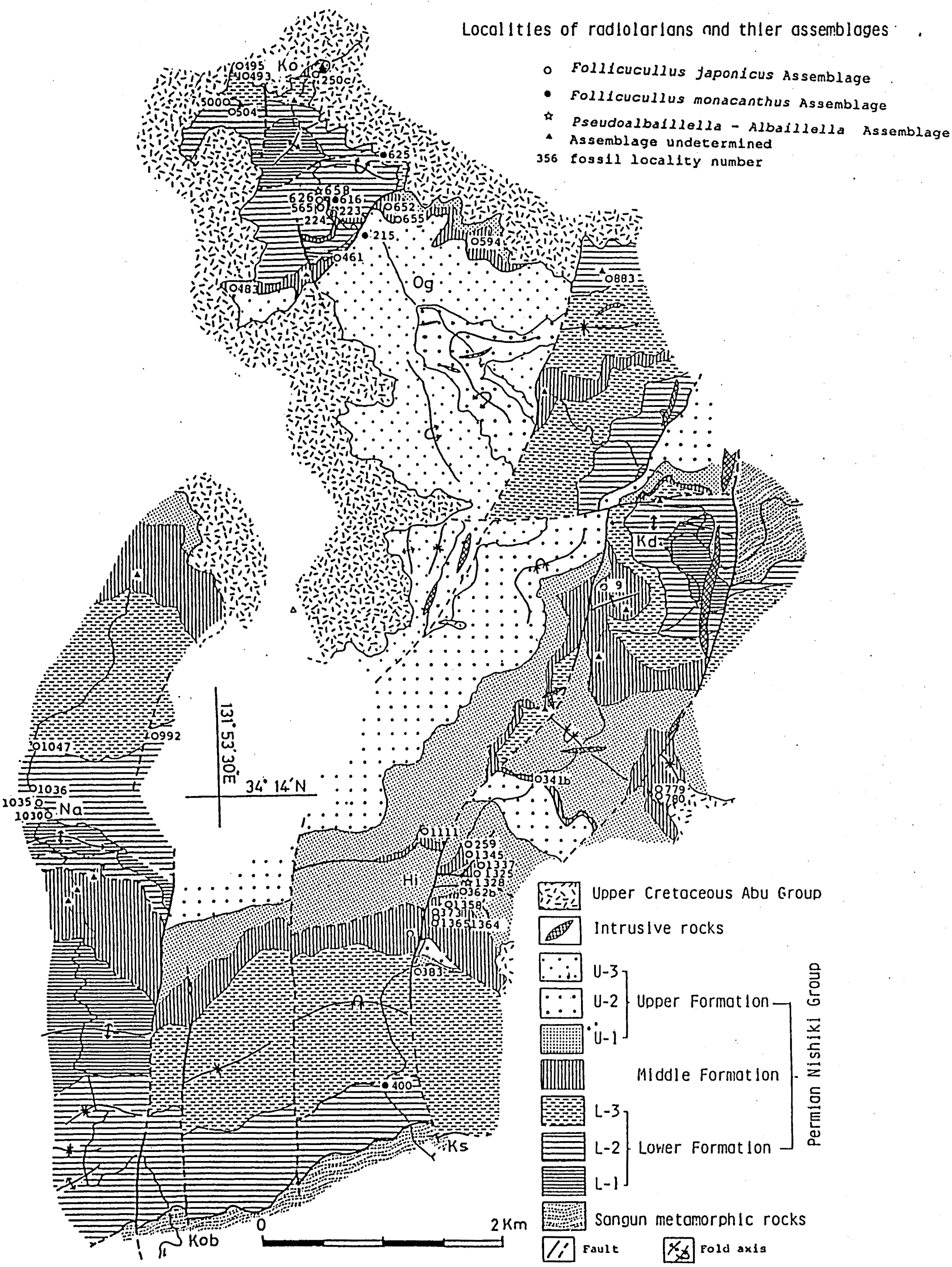


Fig. 9 : A geologic map of the Nishiki area and showing radiolarian fossil localities and assemblages (modified from Naka, 1987MS). Mapped area is shown in Fig. 7.

IV. Lithostratigraphy of Carboniferous to Permian succession

The lithostratigraphies of the Upper Carboniferous to Permian siliceous and terrigenous clastic rocks, and stratigraphy of the Carboniferous to Permian Atetsu Limestone are described in this Chapter.

The Upper Carboniferous to Permian siliceous and terrigenous clastic rocks in the Atetsu region are distinguished into three formations and three complexes; Terauchi, Fuyori, and Ishiga Formations, and Taniai, Kamiya, and Yotsuune Complexes. They are grouped into three major lithostratigraphical and structural types as already mentioned in the Chapter III, namely the Terauchi, Fuyori and Taniai Types (Fig. 4).

A comparative scheme of the stratigraphy of previous workers with this work in the Atetsu region is given in Tables 1, 2, 3 and 4.

A. Terauchi Formation

(*Terauchi Type*: redefined from Motizuki, 1938 and Otoh, 1987)

Name : The formation name was derived from the name of place, Terauchi, located in the eastern Niimi City, Okayama Prefecture (Figs. 3 and 11).

Historical background : The Terauchi Formation was introduced by Motizuki (1938) for clastic rocks lying on limestones. Otoh (1987) broadly followed Motizuki, but preferred to call the formation as Terauchi Group (Table 1).

Table 1 : A comparative scheme of the stratigraphy of previous workers with this work in Terauchi area.

This study		Sada (1965) Okimura *et al.*(1981)		Otoh (1987)
Taniai Type	Kamiya Com.	Terauchi Fm.	Yukawa Group	Terauchi Group
Terauchi Type	"Northern" Terauchi Fm.			?
Atetsu Limestone (Northern Facies)	Maki Fm.	Maki Fm.		Sabuse Fm.
	Shoyama Fm.	Shoyama Fm.	Sabushi Group	
	Iwamoto Fm.	Iwamoto Fm.		
	Kodani Fm.	Kodani Fm.	Mitsudo Group	Kodani Fm.
	Nagoe Fm.	Nagoe Fm.		Nagoe Fm.

Abbreviation : Com., Complex ; Fm., Formation
Stratigraphic relationship : ——— fault ; — — conformiy ; —— — —— — unconformity or brake of sedimentation

A sequence of clastic rocks covering on the Southern Facies of the Atetsu Limestone was discovered in several areas, and was named tentatively as the Kurauchi Formation by Naka (1989), and here referred as the "Southern" Terauchi Formation due to its distinct lithofacies from the north sector. Accordingly the name Kurauchi Formation is abandoned.

Table 2 : A comparative scheme of the stratigraphy of previous workers with this work in Azae to Mio area.

This study		Okimura *et al.*(1981)		Otoh (1987)
Triassic strata				
Terauchi Type	"Southern" Terauchi Fm.			
Atetsu Limestone (Southern Facies)	Maki Fm.	Maki Fm.	Yukawa Group	Sabuse Fm.
	Shoyama Fm.	Shoyama Fm.	Sabushi Group	
	Iwamoto Fm.	Iwamoto Fm.		
	Kodani Fm.	Kodani Fm.	Mitsudo Group	
	Nagoe Fm.	Nagoe Fm.		Yotsuune-yama Chert Fm.
Fuyori Type	Fuyori Fm.	Yotsuune Fm.		Fuyori Fm.
metamorphic rocks (Suo Terrane)		metamorphic rocks		

Abbreviation : Com., Complex ; Fm., Formation
Stratigraphic relationship : ——— fault ; — — conformiy ; —— — —— — unconformity or brake of sedimentation

Table 3 : A comparative scheme of the stratigraphy of previous workers with this work in Hanagi to Yotsuune area.

This study		Yoshimura (1961) Okimura *et al.*(1981)		Otoh (1987)
Terauchi Type	"Southern" Terauchi Fm.	Terauchi Fm.	Yukawa Group	
Atetsu Limestone (Southern Facies)	Maki Fm.	Maki Fm.		Sabuse Fm.
	Shoyama Fm.	Shoyama Fm.	Sabushi Group	
	Iwamoto Fm.	Iwamoto Fm.		
	Kodani Fm.	Kodani Fm.	Mitsudo Group	Kodani Fm.
	Nagoe Fm.	Nagoe Fm.		Nagoe Fm.
Fuyori Type	Fuyori Fm.	Fuyori Fm. ?		Yotsuune-yama Chert Fm.
Taniai Type	Taniai Com.	Yotsuune Fm. and Triassic strata		
Triassic strata				Terauchi Group
metamorphic rocks (Suo Terrane)		metamorphic rocks		Hokoku Group (meta. rocks)

Abbreviation : Com., Complex ; Fm., Formation
Stratigraphic relationship : ——— fault ; — — conformiy ; —— — —— — unconformity or brake of sedimentation

Table 4 : A comparative scheme of the stratigraphy of previous workers with this work in Ishiga to Ikura area.

This study		Motizuki (1938)	Sada (1965)	Okimura *et al.* (1981)	Otoh (1987)	Takeda and Nishimura (1989)
Atetsu Limestone (Northern Facies) ~ Terauchi Fm.		Toyonaga Fm.	Nagoe Fm.~ Terauchi Fm.	Atetsu Limestone (Norththem Facies) / Ishiga Fm.	Nagoe Fm. ~ Terauchi Group	
Atetsu Limestone (Southern Facies) Nagoe Fm. ~ Iwamoto Fm.			Sabushi Group: Iwamoto Fm.; Mitsudo Group: Kodani Fm.	Atetsu Limestone (Southern Facies) Nagoe Fm. ~ Iwamoto Fm.	Nagoe Fm. ~ Sabuse Fm.	
Fuyori Type	Ishiga Fm.	Ishiga Fm.	Ishiga Fm.		Terauchi Group	Ishiga Fm.
Atetsu Limestone (Southern Facies)	Iwamoto Fm.	Ikura Fm.	Crystalline limestone Kodani and Iwamoto Fm.	Crystalline limestone	Kodani Fm.	Ikura I Fm.
	Kodani Fm.				Nagoe Fm.	
	Nagoe Fm.				Kodani Fm.	Ikura II Fm.
					Nagoe Fm.	
Fuyori Type Fuyori Fm.	*Taniai Type* Taniai Com.	Taniai Fm.	Ishiga Fm.	Fuyori Fm.	Fuyori Fm.	Taniai Fm. Iwanaka Fm.
metamorphic rocks (Suo Terrane)			Taniai phyllite Group		Hokoku Group	Oojaridani Fm.

See the abbreviations and stratigraphic relationships of Table 1.

Lithology	Color	Stratification	Radiolarians	Sponge spicules	Clastic quartz & plagioclase	Volcanic glass
chert (radiolarian chert)	mainly red with green, pink	Well bedded with thin mud film, rarely massive	⬤	•		
spicular chert	white, grey, green to pale green	Massive or rarely bedded with limestone and silicic tuff	•	⬤		
silicic tuff	green to pale-green, orange	Bedded or well-bedded, grades upward to siliceous mudstone	•	•	●	•
siliceous mudstone	grey to black	Bedded, with silicic tuff, mudstone and sandstone	●	•	⬤	

⬤ : abundant ● : common • : rare or trace

Fig. 10 : Criteria for the differentiation of the four fine-grained siliceous rocks.

Redefinition : The Terauchi Formation is characterized by the terrigenous clastic sequence resting upon the Atetsu Limestone.

Lithofacies: The Terauchi Formation is divided into the Northern and Southern facies as already mentioned in the Chapter III, and lithostratigraphical and structural characters, and their generalized lithostratigraphical columns are summarized in Figs. 4 and 5, respectively.

1. "Northern" Terauchi Formation

Stratotype : The holostratotype is the road cutting from Shoyama through Yukawa to Terauchi (lower half of C route and middle part of B route, Fig. 13), Terauchi area.

Distribution : The "Northern" Terauchi Formation is mainly distributed in Terauchi area (Fig. 11) and Hirose area (Fig. 14), moreover crops out in the north of Dobashi, south of Niimi, and west of Ishiga (Fig. 3).

Thickness : 450m in the holostratotype, 400m in route A in Fig. 12, 500m+ in Hirose area.

Description : The "Northern" Terauchi Formation is divided into the Lower and Upper Members based on the proportion of sandstone/mudstone and presence of limestone conglomerates.

a. Lower Member

The Lower Member consists mainly of alternating beds of light gray sandstone and black to dark gray mudstone, subordinated by silicic tuff and/or spicular chert in the lower horizon, as developed in Terauchi area, especially in Area A of Fig. 11. The member is generally 100 meters in thickness (Fig. 13). The member in the Hirose area also shows the same lithology but thinner and more restricted distribution of silicic tuff. The presence of conglomerates of various-sized limestone gravels characterizes the member. Mudstone and limestone conglomerates are thicker in the Hirose area than those of in the Terauchi area.

The lower succession of sandstone and mudstone alternations is highly calcareous. A single bed of the sandstone and mudstone is generally 5 to 10 centimeters thick, occasionally their thickness varies from 2 to 30 centimeters. Silt partings are also present in some sandstone beds.

Massive sandstones occur in a close association with the limestone conglomerates. The sandstones are fine to medium-grained, white-gray colored, and contain small fragments of limestone and individual fusulinid tests.

The thickness of the mudstone-dominated sequence of the Lower Member varies from 20 meters in Terauchi area, to 140 meters in Hirose area. The mudstones are in general thin laminated and/or poorly stratified. Mudstones, with poor stratification, contain dispersed limestone clasts, sometimes individual fusulinid tests, ranging in size from 0.5 to 10 centimeters in diameter.

Limestone conglomerates are commonly embedded in the matrix of dark gray to black mudstone and calcareous mudstone. Clasts of conglomerate are poorly sorted, subrounded and variously sized (20 centimeters in diameter to ultra-fine). Small amount of clasts of marlstone and calcareous sandstone is also present. Laterally limestone conglomerates show an abrupt change to other lithofacies, either to calcareous sandstone, or to mudstone, or to alternating beds of sandstone and mudstone. The limestone conglomerate is generally 1 to 10 meters thick. In the holostratotype, it is 5 to 40 meters thick (Fig. 13). In Hirose area, however, its extension reaches about 800 meters (Fig. 14). Four horizons of limestone conglomerates can be easily recognized in the holostratotype section of Terauchi area (Fig. 13), whereas in the Hirose area the presence of three bands is noticeable (Fig. 14).

A massive and recrystallized limestone lens of 220 meters length and maximum thickness 80 meters is present in the northwest of Iwamoto, in the Terauchi area within the member. Its lithofacies are quite different from those of the limestone conglomerate (Fig. 11).

Spicular chert* and fine-grained silicic tuff* were found form the basal part of the member (* : The differentiation among radiolarian chert, spicular chert, silicic tuff, and siliceous mudstone is summarized in Fig. 10). Spicular chert and silicic tuff are dark gray, dark green, and pale green, generally stratified, appears in beds ranging 3 to 10 centimeters in thickness. In some case they are intercalated by 1 to 5 centimeters thick calcareous mudstone. The basal part is however traceable in a limited distance in Terauchi and Hirose areas.

b. Upper Member

The Upper Member mainly consists of sandstone and sandstone dominated alternating beds of sandstone and

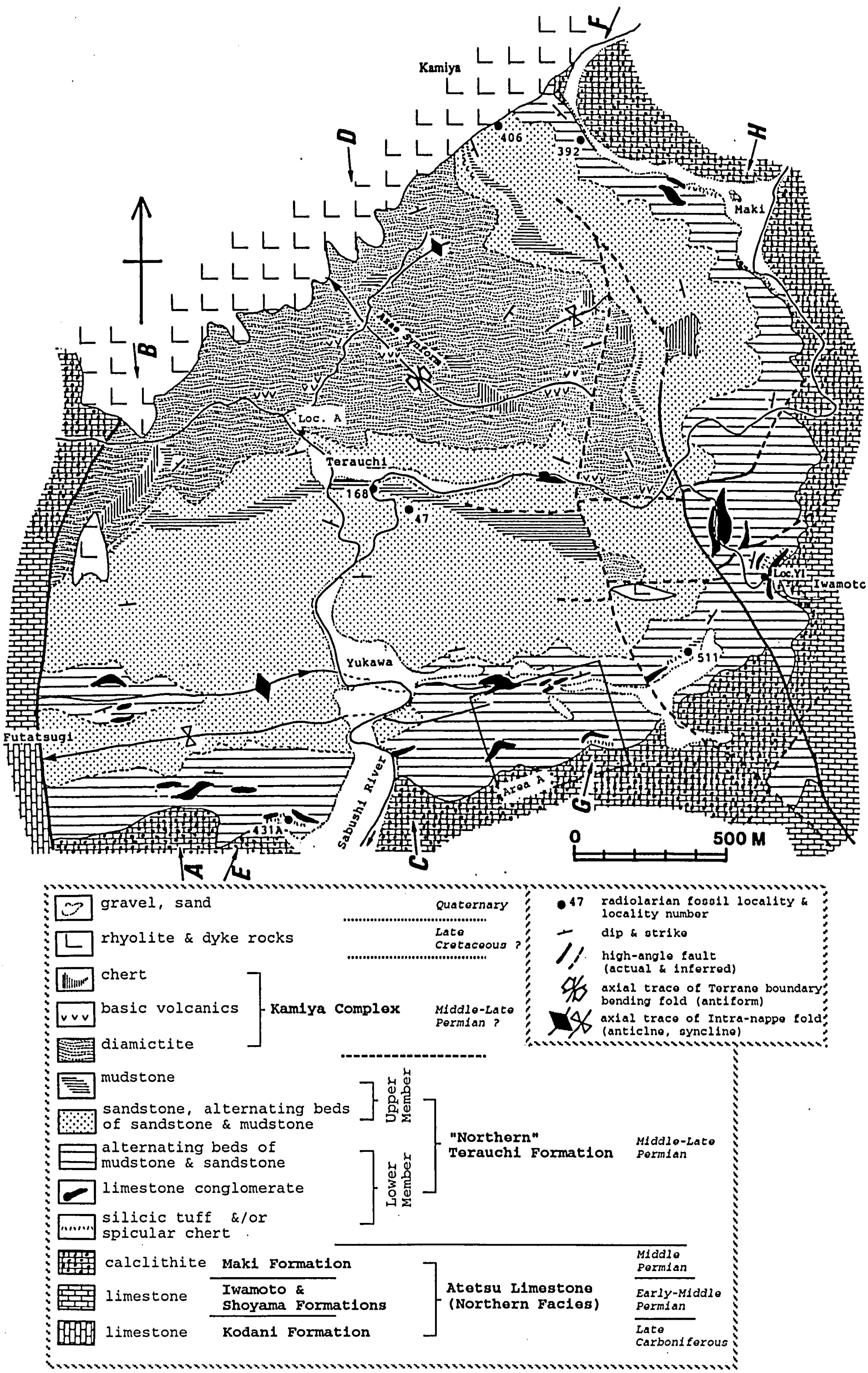


Fig. 11 : A geologic map of the Terauchi area. Mapped area is shown in Fig. 3.

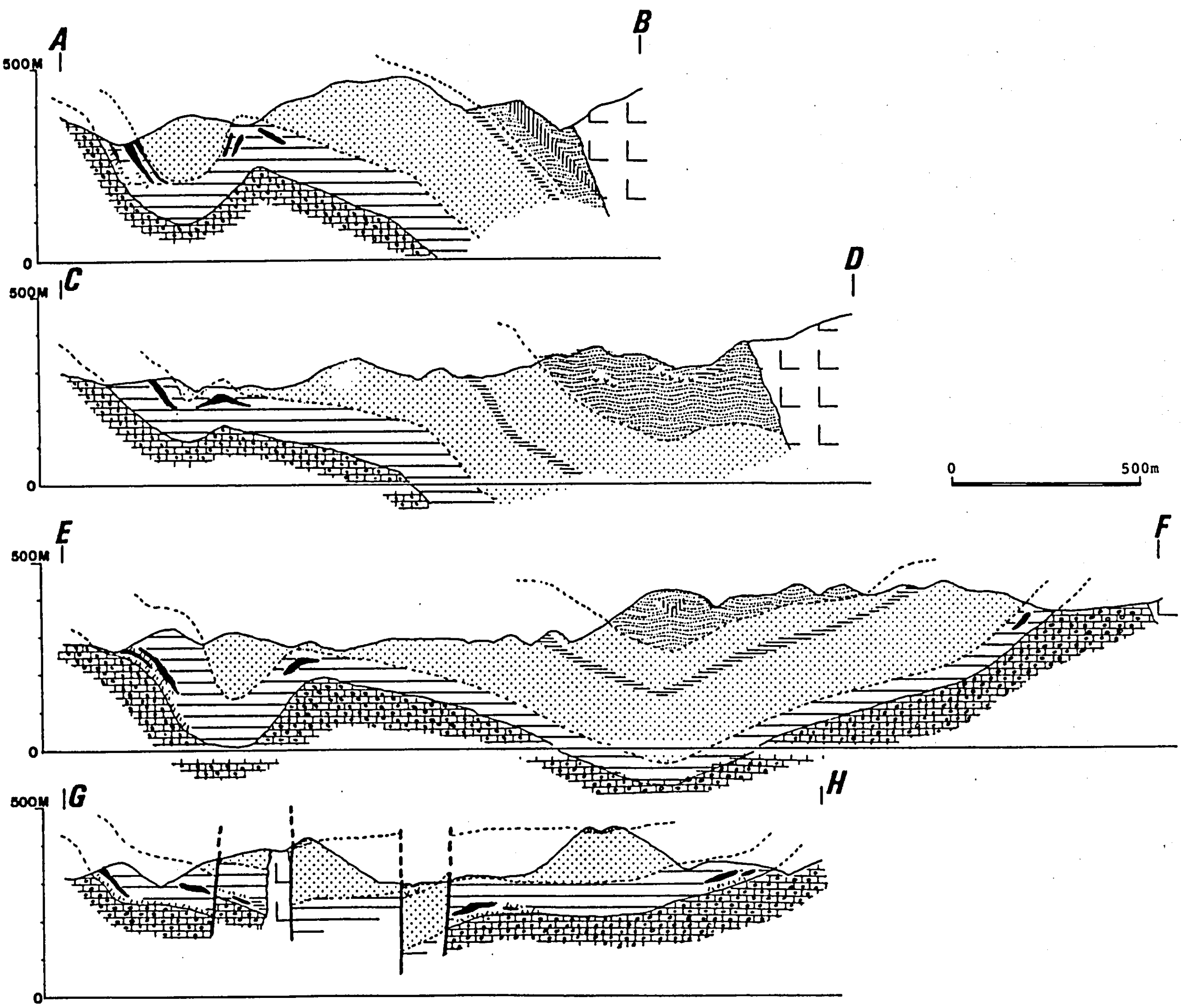


Fig. 12 : Geologic cross sections of the Terauchi area. See the legend and section lines of Fig. 11.

mudstone associated with mudstone. In Terauchi area, the succession is clear and is generally 350 meters in thickness, whereas in Hirose area, sandstone is only developed in areas where it is canceled below a thick pile of rhyolite.

The sandstones are whitish gray to gray, massive, medium to fine-grained and rarely interbedded with mudstone. The sandstones are lithic wacke type, with fragments of silicic tuffs and volcanic rocks (Plate 8-4 a-b).

A mudstone layer, less than 50 meters thick, is intercalated in the upper horizon of the member, and can serve a useful key bed for dividing the member into lower and upper parts (Fig. 13).

In the upper part of sandstone layer, in the east of Terauchi, recrystallized massive limestone body occurs. The contact between limestone and sandstone is a fault, though minor. No fossil could be found in the limestone.

Structure : The "Northern" Terauchi Formation as well as underlying the Atetsu Limestone and overlying the Kamiya Complex forms a synform (Azae Synform; Figs. 11 and 12; see Chapter VI) with slight to moderate plunging to the W or NW in Terauchi area. The northern limb, presented by distribution of the "Northern" Terauchi Formation generally strikes to NW or N with moderate dips to the west. The southern limb, have general strikes to ENE, and moderate dip to the N. In the lower member, however, there are a set of minor syncline and anticline (Intra-nappe folds : see Chapter VI) trending ENE-WSW with a half wavelength of 200 to 300 meters long (Figs. 11 and 12).

In Hirose area, the "Northern" Terauchi Formation forms a homoclinal structure with the NW-SE or WNW-ESE general trend and moderate dip to N (Fig. 14).

Stratigraphic relationship : The contact between the "Northern" Terauchi Formation and the underlying Northern Facies of the Maki Formation (Atetsu Limestone) is not exposed. However, the general geologic structures and distributing patterns of the two formations are harmonic. Moreover, spicular chert characterizing the lowermost horizon of "Northern" Terauchi Formation is also present as distinct layers of 50 centimeters thick in the middle part of Maki Formation, in Futatsugi, Terauchi area. The calclithite (brecciated limestone), a representative of the Maki Formation, occurs as lenticular bodies in the

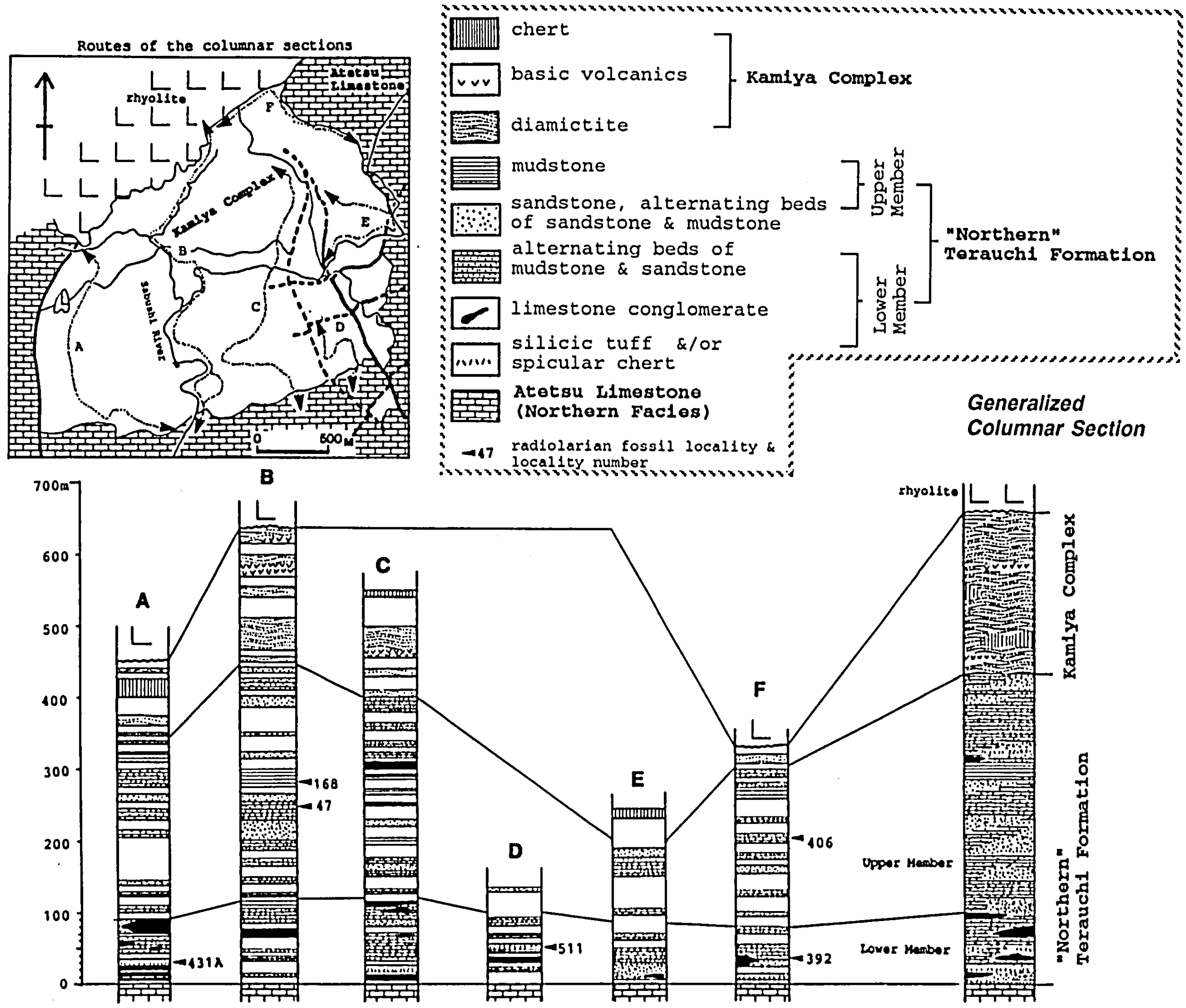


Fig. 13 : Geologic columnar sections of the "Northern" Terauchi Formation and the Kamiya Complex of the six routes in the Terauchi area. A generalized columnar section of two rock units is also given (lower-right). The routes of columnar sections are shown in upper-left.

Terauchi Formation. These observations thus suggest a conformable relationship and gradational facies change between the formations.

Fossils : The Lower Member is characterized by the Middle to Late Permian radiolarians found in Terauchi and Hirose areas (see Chapter V). Yamashita and Ishiga (1990) reported the Middle Permian radiolarians from the lowermost part of the formation. Abundant fusulinid and smaller foraminiferal fossils have also been reported from limestone conglomerates in the Lower Member (Sada, 1960; Sakagami and Miyama, 1988).

Remarks : Sada (1960) recognized four horizons of lenticular limestone conglomerate), namely H2, H3, H4 and H5, in Terauchi area. The interpretative correlation between Sada (1960, 1965) and the present work for this is discussed in the Chapter V.

Sakagami and Miyama's (1988) sedimentological study of the limestone conglomerates in the Terauchi area, pointed out that the: 1) gravels are mainly subangular in shape and muddy limestone in lithology, 2) texture is the clast-supported type, and the matrix is composed of poor-sorted calcareous mud, 3) two types of conglomerate members are recognized, that are poor-sorted gravels and relatively well-sorted ones. The depositional setting of the limestone conglomerates will be discussed in the Chapter VIII.

2. "Southern" Terauchi Formation

Stratotype : The holostratotype is a short valley with an N-S trend, located in Arasako, Hokubou Town, Okayama Prefecture (Fig. 15).

Distribution : The "Southern" Terauchi Formation is scattered at Arasako, Kurauchi, Azae, Kanikawa, Tochio and Idono (Figs. 3, 15, 16, and 18).

Thickness : 55m in Arasako section (holostratotype), 60m in Azae section, 50m+ in Kurauchi section, 20m+ in Tochio area, and 50m+ ? in Idono area.

Description : In Arasako section (holostratotype), the lower half of the formation consists of 25 meters thick bedded spicular chert intercalated with two lenticular limestone conglomerates (each conglomerates up to 0.5 meters thick) and 3.2 meters thick calclithite bodies. The

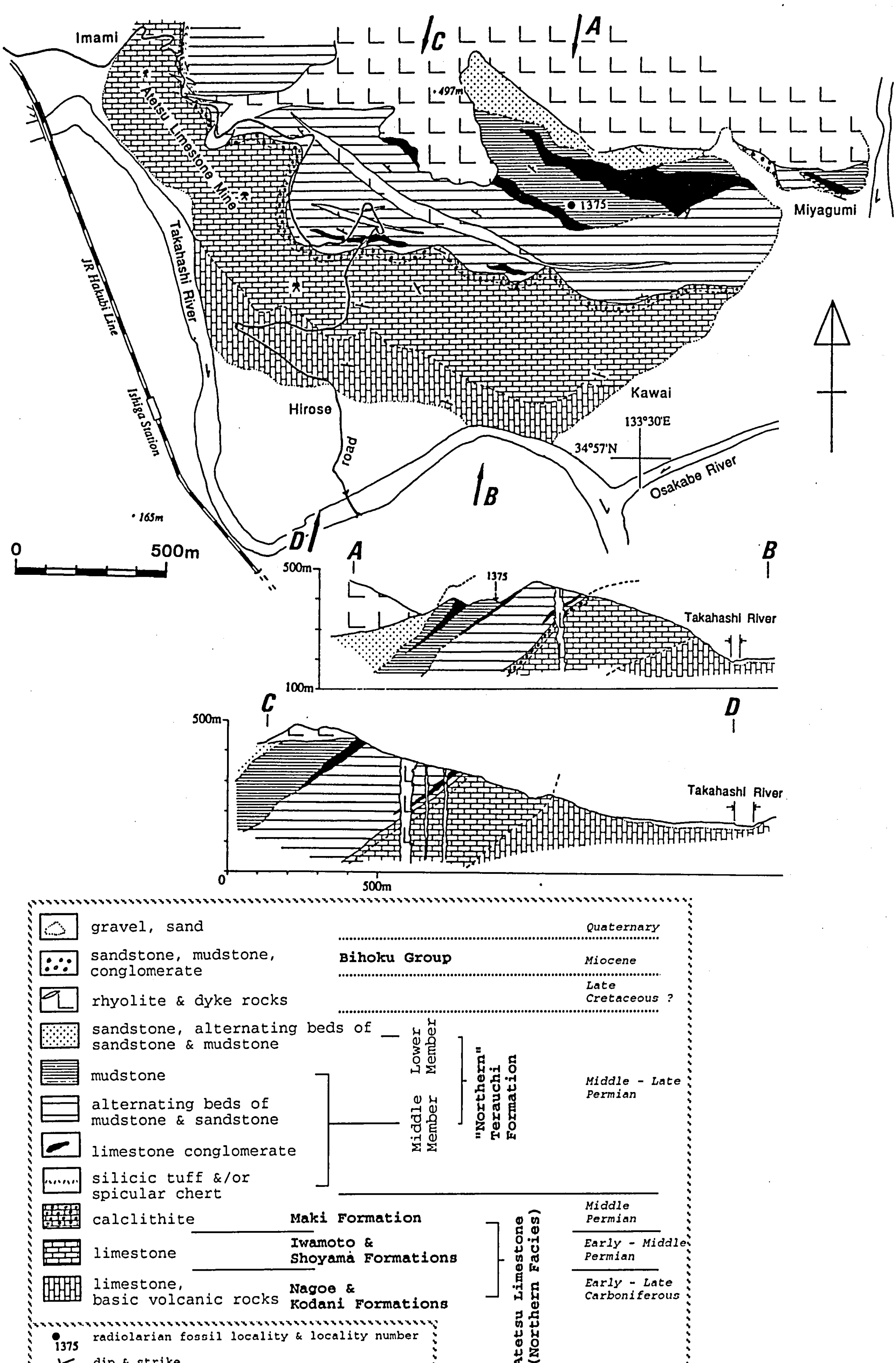


Fig. 14 : A geologic map and cross sections of the Hirose area. Mapped area is shown in Fig. 3.

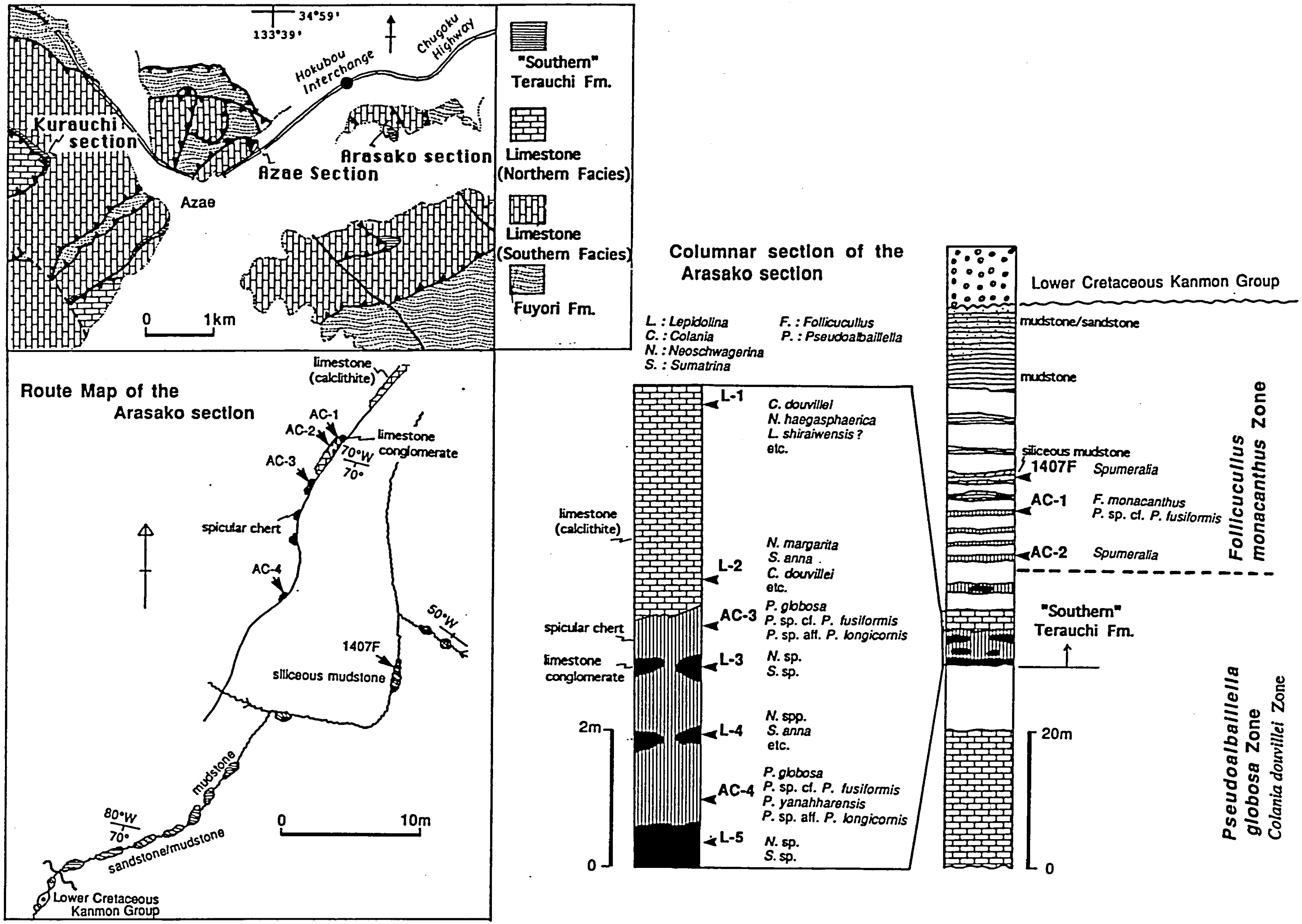


Fig. 15 : A route map of the Arasako section (lower-left inset figure) and columnar section (right) of the Arasako section including holostratotype of the "Southern" Terauchi Formation. Route map and columnar section show the sampled localities and horizons of radiolarian and fusulinid fossils. The area of the route map is shown in upper-left inset figure and also in Fig. 3.

upper half is composed of siliceous mudstone, mudstone and alternating beds of mudstone and sandstone (Fig. 15). In Azae section, the lower half is characterized by less than 25 meters thick rhythmic alternation of silicic tuff and limestone conglomerate, and upper half by thick alternating beds of silicic tuff and siliceous mudstone, and mudstone and minor amount of limestone conglomerate (Fig. 28).

The spicular chert (Plates 8-6a, b)and silicic tuff are very hard, and dark gray, dark green, and pale green in color. In Azae section, pale greenish silicic tuffs are interbedded with limestone conglomerate of 10 to 20 centimeters thick. Usually the conglomerate grades into tuffaceous rocks.

The lowermost part of limestone conglomerates contains fossils and silt to sand size limestone fragments. The lithology of limestone conglomerate is somewhat different from that of in the "Northern" Terauchi Formation. Matrix of conglomerate is relatively little and composed of calcareous mud rarely containing terrigenous quartz grains. Sorting of gravels is relatively well. The limestone conglomerates in upper half of the formation in Kurauchi and Azae sections exhibit the similar lithologic features to those in the "Northern" formation. The difference is found in thickness, but they are only 5 meters thinner than those in the "Northern" formation.

The mudstone is mostly siliceous, and acquires calcareous nature near the horizons of limestone conglomerate. Sandstone is calcareous, abounds with limestone fragments, and mainly occurs in the lower horizons of Kurauchi section.

Structure : The "Southern" Terauchi Formation in Arasako section (holostratotype), forms a homoclinal structure with a general E-W to NW-SE trend and steeply dips to S (Fig. 15). In Azae section, it trends NWN-SES or NW-SE, dipping steeply westward or northeastward as seen in grading structure of alternating beds of silicic tuff and siliceous mudstone (Fig. 18). In Kurauchi section, it trends NW-SE and moderately dips southward in north area, while in south area it trends NE-SW and dipping to the north, thus it forms an axis of a synform (Azae Synform; Fig. 18; see Chapter VI).

Stratigraphic relationship : The boundary between the "Southern" Terauchi Formation and the underlying Southern Facies of the Maki Formation (Atetsu Limestone) is placed on the horizon of the disappearance of distinct calclithite (brecciated limestone) and appearance of bedded silicic tuff and/or spicular chert. The exact contact between the two formations could not be observed. However, the structural concordance and gradual lithological change suggest that the "Southern" Terauchi Formation conformably overlies the Maki Formation.

The upper limit of "Southern" Terauchi Formation is probably eroded because the formation is unconformably overlain by the Early Cretaceous Kanmon Group, or is truncated by the faults.

Fossils : The "Southern Terauchi Formation yields the Middle to Late Permian radiolarians, fusulinids and smaller foraminifers (see Chapter V).

B. Fuyori Formation

(*Fuyori Type* : redefined from Ministry of International Trade and Industry : abbreviated as MITI, 1968; Otoh, 1987)

Name : The formation name derived from place, Fuyori, located in Tetta Town, Okayama Prefecture (Fig. 3).

Historical background : The formation was first introduced informally by MITI (1968) in the geological map of the Fuyori area. Otoh (1987) restricted the formation for the Permian clastic strata in the Atetsu region. Chert yielding the Late Carboniferous conodonts was separated from the Fuyori Formation and was defined as the Yotsuune-yama Chert Formation (Otoh, 1987). The stratigraphic division of this paper, however, is different from that of Otoh (1987; see Table 2, 3 and 4).

Redefinition : The Fuyori Formation is here redefined as Upper Carboniferous to Permian sedimentary rocks including cherts, which is in a fault (mostly thrust) contact with the Atetsu Limestone.

Lithologic characters : The Fuyori Formation is characterized by the stratigraphic succession from the lower chert, the middle siliceous mudstone, silicic tuff, mudstone, to the upper sandstone and alternating beds of sandstone and mudstone (Figs. 6 and 20).

Stratotype : The Fuyori Formation in Fuyori area was not surveyed in detail by the author, however the succession of the formation in Azae area shows relatively complete stratigraphy more than the other surveyed areas. The holostratotype, therefore, is tentatively placed along the valley in N-S trend from Shiroyama to Azae, Azae area (Fig. 18).

Distribution : The formation is intermittently distributed in a belt of an NW-SE trend from Mio to Azae areas (Figs. 16 and 18), and in area of a ENE direction from Azae through Mochidani to Ikura, and also in area of the same direction from Fuyori to Mt. Tenjin in further WSW (Figs. 3 and 19). The formation also crops out in Yotsuune and Hanagi areas having a ENE - WSW direction (Figs. 3 and 19).

Thickness : 350m+ in Azae area (holostratotype), 400m+ ? in Mio area, 300m+ ? in Mochidani area (Fig. 20).

Description : The stratigraphies, dominant lithologies and structures are various in different sectors separated by faults. Therefore the lithology and lithostratigraphy of each area are separately described. The lithostratigraphic correlation of the Fuyori Formation of different areas is summarized in Fig. 20. The biostratigraphical correlation of each fault-bounded area is mentioned in Chapter V.

i) Azae area (Fig. 18)

The Azae area exposes the most extensive development of lithology and lithostratigraphy of the Fuyori Formation. The formation consists of chert in the lower part, siliceous mudstone, mudstone, pebbly mudstone in the middle part, and sandstone in the upper part.

Chert is, 100+ meters in thickness, red to light gray, generally well-bedded in 5 to 10 centimeters thick layers intercalated with less than 1 centimeter films siliceous mudstone. Chert is mainly composed of cryptocrystalline quartz and contains various amounts of radiolarians and sponge spicules.

Siliceous mudstone and mudstone are presented in the middle part of the formation, and are 20 to 60 meters in thickness. Light to dark gray siliceous mudstone is mainly composed of detrital grains of quartz and feldspar, and is cut by many thin quartz veins. Parallel laminations can be observed under the microscope. Dark gray to black

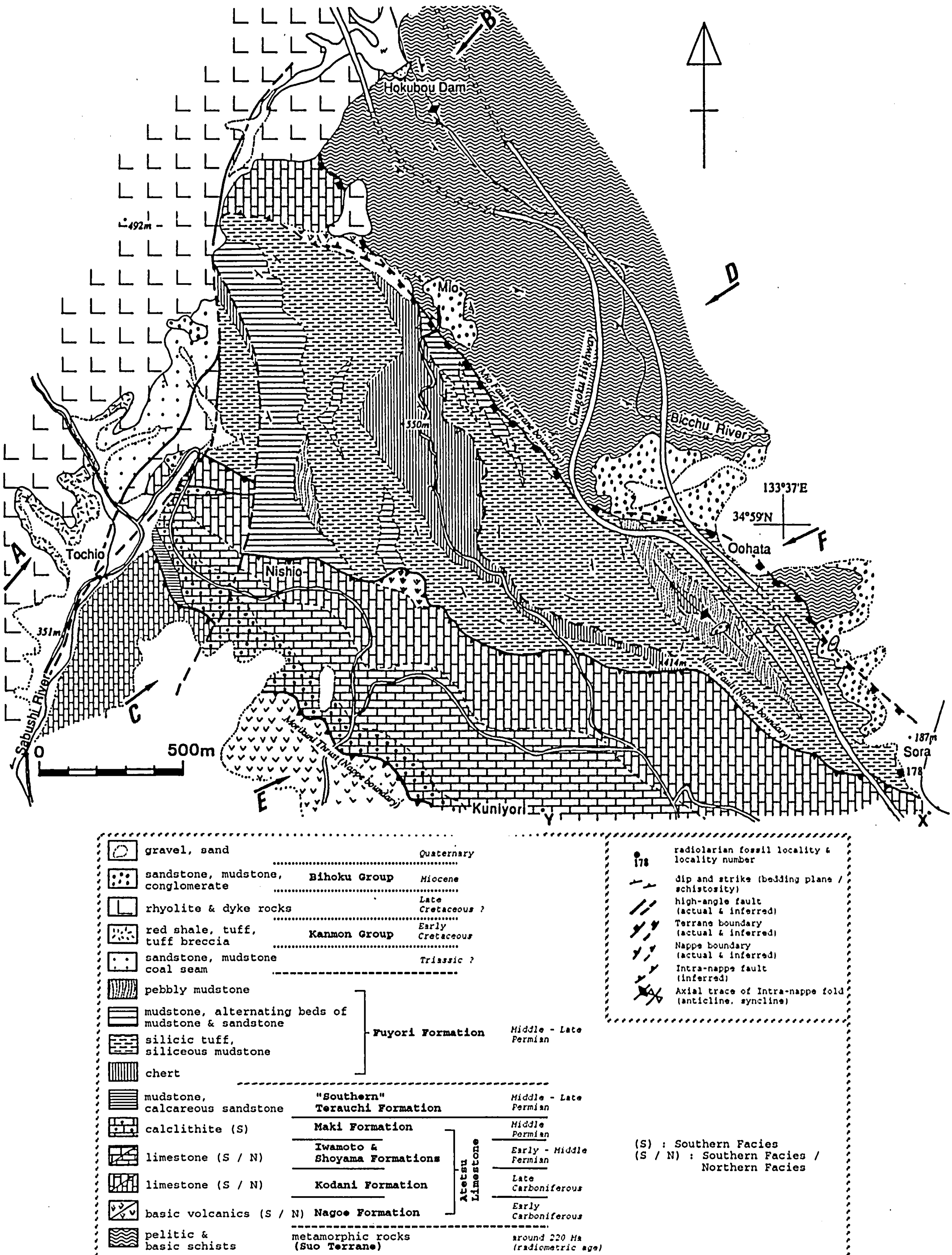


Fig. 16 : A geologic map of the Mio area. Mapped area is shown in Fig. 3.

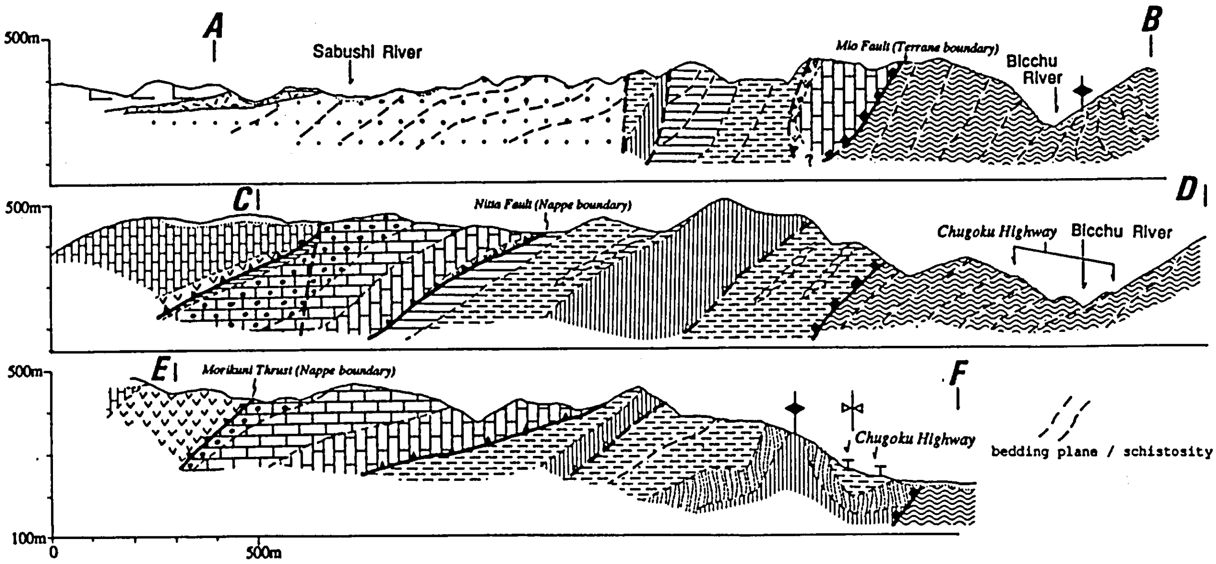


Fig. 17 : Geologic cross sections in Mio area. See legend and section lines of Fig. 16.

mudstone is intercalated with thin sandstone layers in some cases. Some mudstones include fine sand to pebble sized clasts of siliceous mudstone, silicic tuff and sandstone clast, and they are shown in geologic map as pebbly mudstone. The relationship between the lower chert and the middle mudstones considered to be conformable by their gradual lithological change, although the exact contact of the two cannot be observed.

Sandstone, 150 to 240 meters in thickness, is mostly massive, light gray to gray colored. The sandstone, fine to medium grained, is lithic wacke type and abounds of lithic fragments mainly composed of silicic volcanic rocks.

The Fuyori Formation in this area shows quite complicated structures. In north and east of Shiroyama, E-W trending folds can be recognized, while Shiroyama to Azae, the formation forms a syncline and anticline (Intra-nappe folds; see Chapter VI) with axes generally trending N-S. The distribution of the Fuyori Formation forms a horseshoe shape with an eastward convex, showing the axis of synform (Azae Synform; see Chapter VI) plunging westwards. However, the strike and dips of rocks are mostly discordant with the distribution trend of the Fuyori Formation (Fig. 18).

ii) Mio area (Figs. 16 and 17)

The lithology and lithostratigraphy of the Fuyori Formation in this area are almost similar to the Azae area, except for the domination by the middle siliceous mudstone and absence of the upper sandstone.

Chert is mostly gray to reddish gray and more massive than that of Azae area. Siliceous mudstone is also massive and shows no obvious sedimentary structure in field. The upper sandstone layers were not observed in this area. It can probably be ascribed to the presence of a large number of local faults.

The Fuyori Formation has a general strike of NNW-SSE or NW-SE and a moderate to steep dip to the west or south in this area. An anticline and a syncline (Intra-nappe folds) are present with the half wavelength of 150 meters. A strike thrust (Intra-nappe fault; see Chapter VI) almost parallel to bedding is developed within the formation causing repetition of distribution of the chert and siliceous mudstone.

iii) Nitta to Tarumi area (Fig. 18)

The distribution of the Fuyori Formation in this area is relatively narrow and separated by faults. The formation consists of bedded chert and siliceous mudstone of the lower and middle part. Reddish brown to dark red basaltic tuffs and lavas, approximately 10 meters thick, associated with blocks of gray chert of 50 centimeters long and 10 centimeters wide occur in Tarumi (Loc. A in Fig. 18). The siliceous mudstone is frequently associated with thin layered or irregular bands of silicic tuff.

Axes of the intra-nappe folds in the area have a general trend of NW-SE. The boundary with the Atetsu Limestone has a trend of NE- SW, which truncates the axes of the intra-nappe folds.

iv) Mochidani area (Fig. 19)

The formation in the area mainly consists of siliceous mudstone embedded with silicic tuff layer, and small (less than 10 meters square) blocks of chert and basaltic rocks. In some cases, the siliceous mudstone and silicic tuff show a rhythmical alternation of beds ranging 5 to 15 centimeters thick. The grading is commonly found from the lower silicic tuff to upper siliceous mudstone.

The strata generally trend ENE-WSW and dip northward and southward. A gentle folding is presumed, because the exposed rocks mostly represent the same horizon of the formation.

v) Kusama area (Fig. 19)

The formation is composed of siliceous mudstone, mudstone, and alternating beds of sandstone and mudstone. Their lithofacies are similar to the rocks in Mochidani except for a remarkable presence of sandstone layers and local affections of a weak thermal metamorphism. The formation generally strikes from E to W and dips to N.

vi) Fuyori to Mt. Tenjin and Fukiya areas (Fig. 3)

The formation consists of light gray to reddish gray chert, siliceous mudstone, alternating beds of siliceous mudstone and silicic tuff, and sandstone. The exact stratigraphy is difficult to be constructed because of the disruption by minor faults and folds. The chert exceeds 300 meters in thickness in Mt. Tenjin. The alternating beds of light gray siliceous mudstone and pale green to reddish gray silicic tuff are well developed to 20-40 meters in thickness in west of Mt. Tenjin and Fukiya areas (Fig. 20). A single bed of the siliceous mudstone and silicic tuff is 5 to 10 centimeters thick and shows grading from tuffaceous base to muddy top. Devitrified volcanic glass can be observed in the lower part of tuff beds in west of Mt. Tenjin.

The formation commonly strikes NE-SW in Fuyori to east of Mt. Tenjin, and N-S in west of Mt. Tenjin.

vii) Yotsuune area (Fig. 3)

The formation consists of bedded to massive chert, chert breccia, siliceous mudstone, mudstone, and massive sandstone. Chert breccia observed along the road running from Idono to Nakagumi, is a clast-supported type. The rounded clasts occurring in small amount of siliceous mudstone matrix are mostly chert but are less commonly siliceous mudstone. Chert breccia seems to change gradually to siliceous mudstone in field.

The formation strikes from WSW to ENE and mostly dips to N.

viii) Hanagi area (Fig. 19)

The formation consists of mudstone and siliceous mudstone, that is similar to the formation in Mochidani. However, most of the rocks were strongly affected by a thermal metamorphism, thus it is difficult to construct a proper stratigraphy. The formation probably strikes from WSW to ENE.

Stratigraphic relationship : The Fuyori Formation is in a faults contact with the Atetsu Limestone and metamorphic rocks of the Suo Terrane, and probably with the Triassic strata. The relationship between the Fuyori Formation and the Terauchi Formation is unknown, because the two are not adjacent in any areas.

Fossils : Chert yields the Late Carboniferous conodonts in Ogyou area (Otoh, 1987), and the Middle Permian radiolarians in Azae and Yotsuune areas. Siliceous mudstone, silicic tuff, and mudstone also yield the Middle Permian radiolarians in Azae, Mochidani, and Mt. Tenjin areas (see Chapter V).

C. Ishiga Formation

(*Fuyori Type* : Motizuki, 1938)

Name : The formation name was derived from place name, Ishiga, located in south of Niimi, Niimi City, Okayama Prefecture (Fig. 3).

Historical background : The formation was introduced by Motizuki (1938) for clastic rocks separated from the Atetsu Limestone and it was considered to be overlain by the Atetsu Limestone. MITI (1967) discovered the middle Permian fusulinid fossil, *Yabeina* sp., from the limestone clast embedded in sandstone of the formation. Okimura *et al.* (1981) prepared the geologic map and described the lithostratigraphy of the formation.

Stratotype : The holostratotype section has yet been described by any workers. The author is not either able to set the type locality because of the uncertainty of the stratigraphic position and age.

Distribution : The formation is developed in Ikura, Mt. Daibou to Ogyou areas in NE-SW trend (Fig. 3).

Thickness : approximately 600 meters (Yoshida, 1980MS).

Description : The formation dominantly by massive, lithic wacke type, and gray to light gray sandstone, but is accompanied with a small amount of blocks of basic volcanics and chert in the lower part, and alternating beds of sandstone and mudstone (Fig. 20). Basaltic tuffs and red to dark red chert occur near Ikura. Chert also occurs in Mt. Daibou in a fault contact with sandstone. Alternating beds of sandstone and mudstone with dominance by the sandstone, occur in several outcrops, and show various sedimentary structures, such as grading, parallel lamination, load cast, etc.

Structure : The structure of the formation is not clear, as the dominance in massive sandstone causes poor data of bedding planes. However, the poor data even presumably suggest a gentle folding. Presence of the chert in Mt. Daibou is possibly due to thrusts that lies over the sandstone.

Stratigraphic relationship : The Ishiga Formation is separated from other formations by NE-SW trending high-angle faults and NW-SE trending thrust in north of Ikura area. However in Ogyou, Okimura *et al.* (1981) assumed that the Formation is unconformably overlies the Atetsu Limestone (see Fig. 3). The correlation is difficult because of the probable presence of a large number of faults. However, from the general lithologic features, the formation is presumably correlated to the lower and upper parts of the Fuyori Formation.

Fossils : Fusulinid fossil, *Yabeina* sp., is reported from limestone clasts in sandstone layer (MITI, 1967). No radiolarian fossils have so far been reported from the formation.

Remarks : Sada (1965) reported fossils including *Endothyra* sp. (Carboniferous smaller foraminifer) from limestone lenses in north of Ikura embedded by basic volcanic rocks, and he considered that this formation is underlain by the Atetsu Limestone. However, the lenses are not the member of this formation but are included in the lower part of the Atetsu Limestone from the point of view of lithology and distribution (see Table 4). MITI (1967) divided the formation into three parts, basic volcanics, sandstone, and chert in ascending order, but it is difficult to accept that the chert is conformably overlies sandstone from the point of view of lithology and distribution. Yoshida (1980MS) suggested that the lithology of thick basaltic lava and tuffs in west of Mt. Daibou are closely similar to that of the Nagoe Formation (Atetsu Limestone) and, moreover, these rocks are overlain by the Kodani Formation. Therefore, basaltic lava and tuff layers in west of Mt. Daibou which were included in the lower part of the Ishiga formation by MITI (1967) and Okimura et al. (1981), should be included in the Nagoe Formation as suggested by Yoshida (1980MS).

The modal compositions of 28 sandstone samples of the formation show relatively minor amount of quartz (average 13.3%) and abundant lithic fragments consisting mainly of volcanic rock fragments (average 29.1%) by Okimura *et al.* (1981).

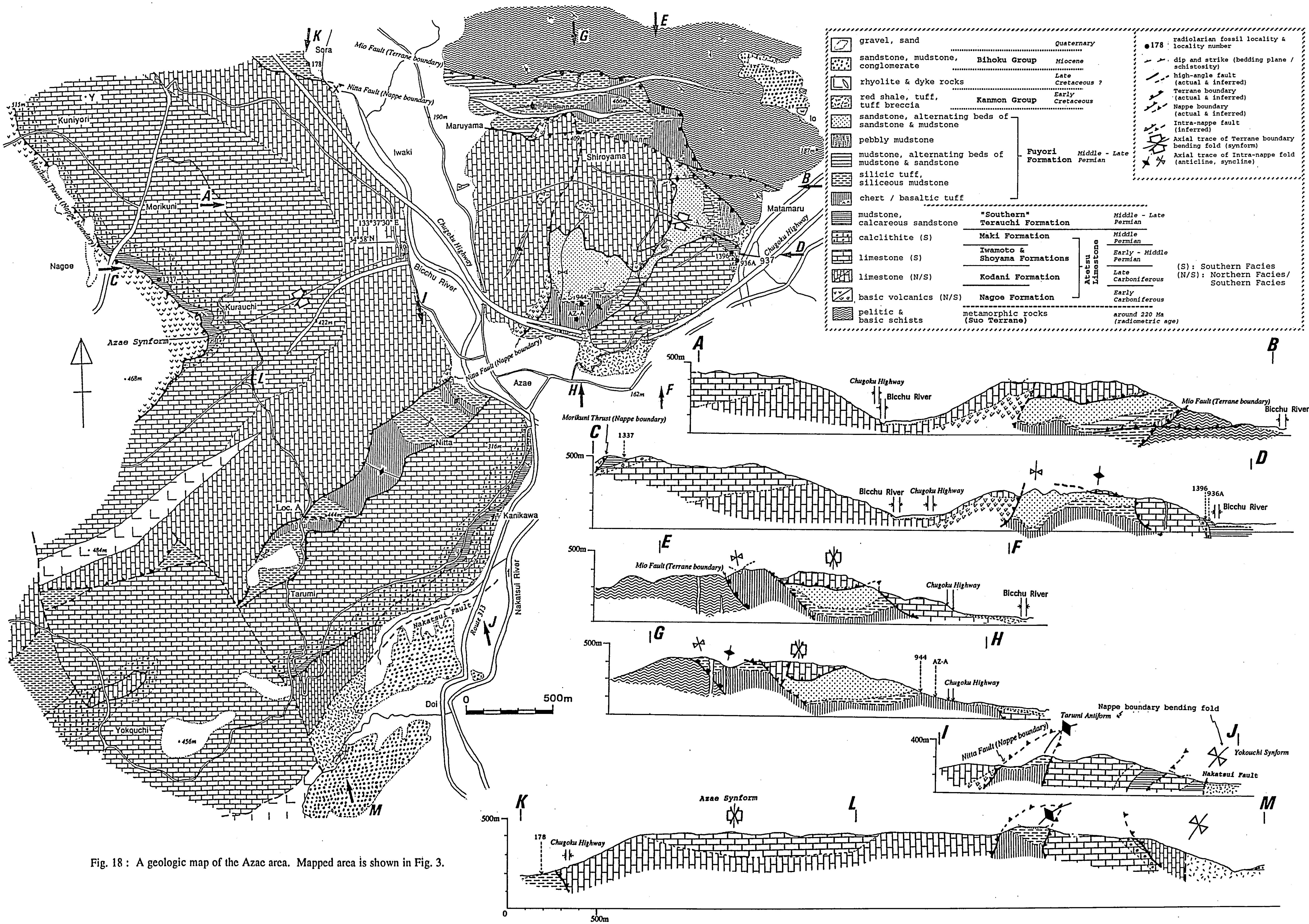


Fig. 18 : A geologic map of the Azae area. Mapped area is shown in Fig. 3.

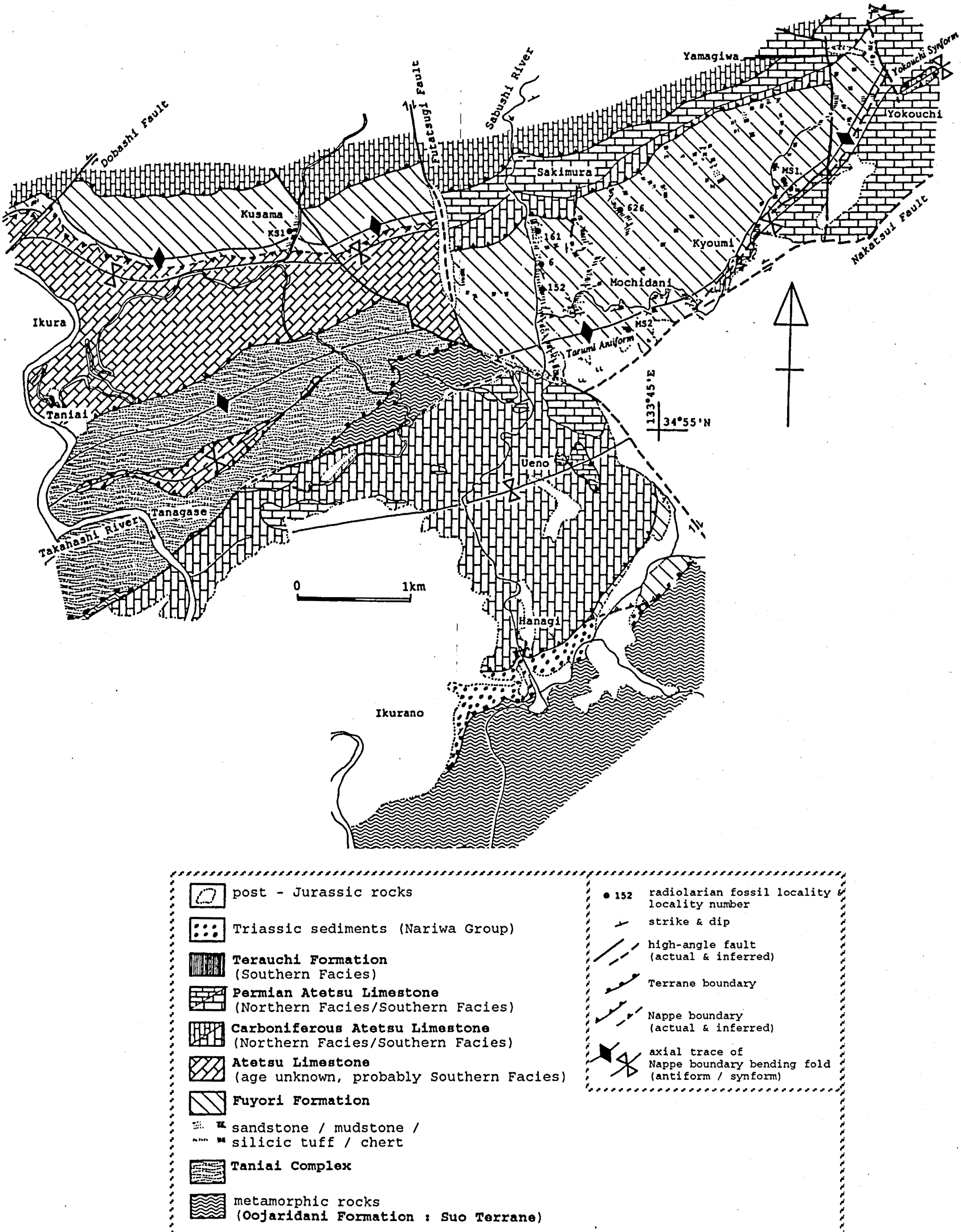


Fig. 19 : A simplified geologic map of the Mochidani, Hanagi and Ikura areas. Mapped area is shown in Fig. 3. Compiled from Takeda and Nishimura (1989; Ikura area) and Sakamoto (1991MS; Hanagi area) with additional author's data.

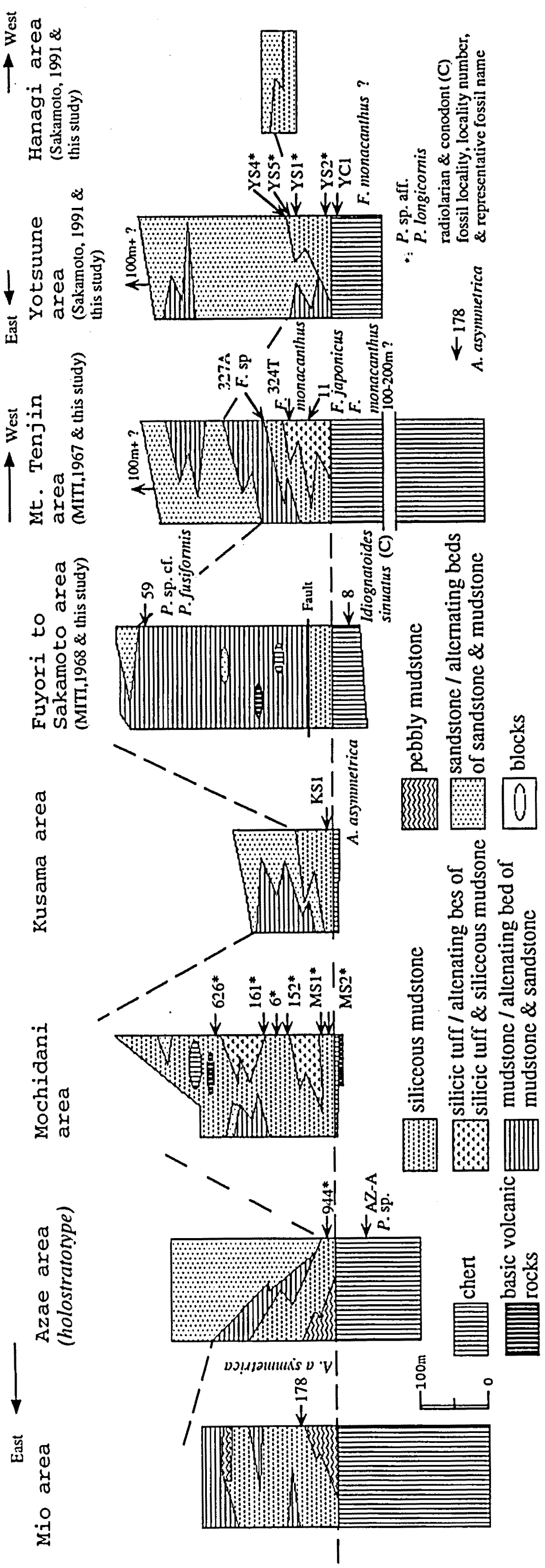


Fig. 20 : Generalized columnar sections of the Fuyori Formation of each fault-bounded area in the Atetsu region. Dashed lines show lithostratigraphical correlation of each area. lower line : boundary between chert (lower part) and siliceous mudstone dominantly part (middle Part), upper line : boundary between siliceous mudstone dominantly part and sandstone dominantly part (upper part). Abbreviations : *A.*, *Albaillella*; *P.*, *Pseudoalbaillella*; *F.*, *Follicucullus*

D. Taniai Complex

(*Taniai Type* : Takeda and Nishimura, 1989)

Name : This name was derived from place name, Taniai, situated in south of Ikura, Niimi City, Okayama Prefecture (Fig. 3).

Historical background : The name Taniai Formation was first used by Motizuki (1938) for relatively deformed and metamorphosed clastic rocks. Takeda and Nishimura (1989) further redefined the formation representing a sedimentary melange (Table 4).

Thickness : Maximum thickness is estimated to be 380 meters (Takeda and Nishimura, 1989).

Description : The Taniai Complex consists of melange deposits including various sized blocks. Some blocks are mappable, while the others can be only recognized under a microscope. The blocks are various in lithology; recrystallized limestone, basic volcanic rocks, recrystallized gray chert, fine grained sandstone, sheared metagabbroic rocks, metagranitic rocks, etc., and the matrix of the melange is black to gray phyllitic mudstone and siliceous mudstone, exhibiting deformational structures, such as lineations and kink-type minor folds. It is noteworthy that the blocks of metagabbroic and metagranitic rocks are embedded in the complex, because they are not found in the Yotsuune and Kamiya Complexes. The complex has undergone stronger deformation and metamorphism than the rocks of the Terauchi and Fuyori Formations.

Structure : The complex generally trends ENE - WSW and dips north- and southward, thus it is presumed to be slightly folded.

Stratigraphic relationship : The Taniai Complex thrusts over the metamorphic rocks named the Oojaridani Formation (Takeda and Nishimura, 1989) of the Suo Terrane and is thrust over by the Atetsu Limestone. The complex is in a high-angle fault contact with the Fuyori Formation.

Fossils : No radiolarian fossils have been found in this formation. Sada (1965) reported *Clisiophyllum* sp. cf. *C. awa*, from a limestone lens in Matsunigo in the Nagoe Formation of the Atetsu Limestone.

Remarks : Takeda and Nishimura (1989) described details of the lithology, chemical composition of metabasic to silicic igneous rocks, and metamorphic grade of the rocks distributed in Ikura area, including the Taniai Complex. According to them, the Taniai Complex is characterized by a sedimentary melange with blocks of various lithologies in a pelitic matrix. The blocks largely consist of limestone, pillow lava with MORB geochemistry, chert, sandstone, and mudstone. The Taniai Complex has undergone glaucophanitic metamorphism, and divided into two metamorphic mineral assemblage zones; the pumpellyite-actinolite zone (lower part of the

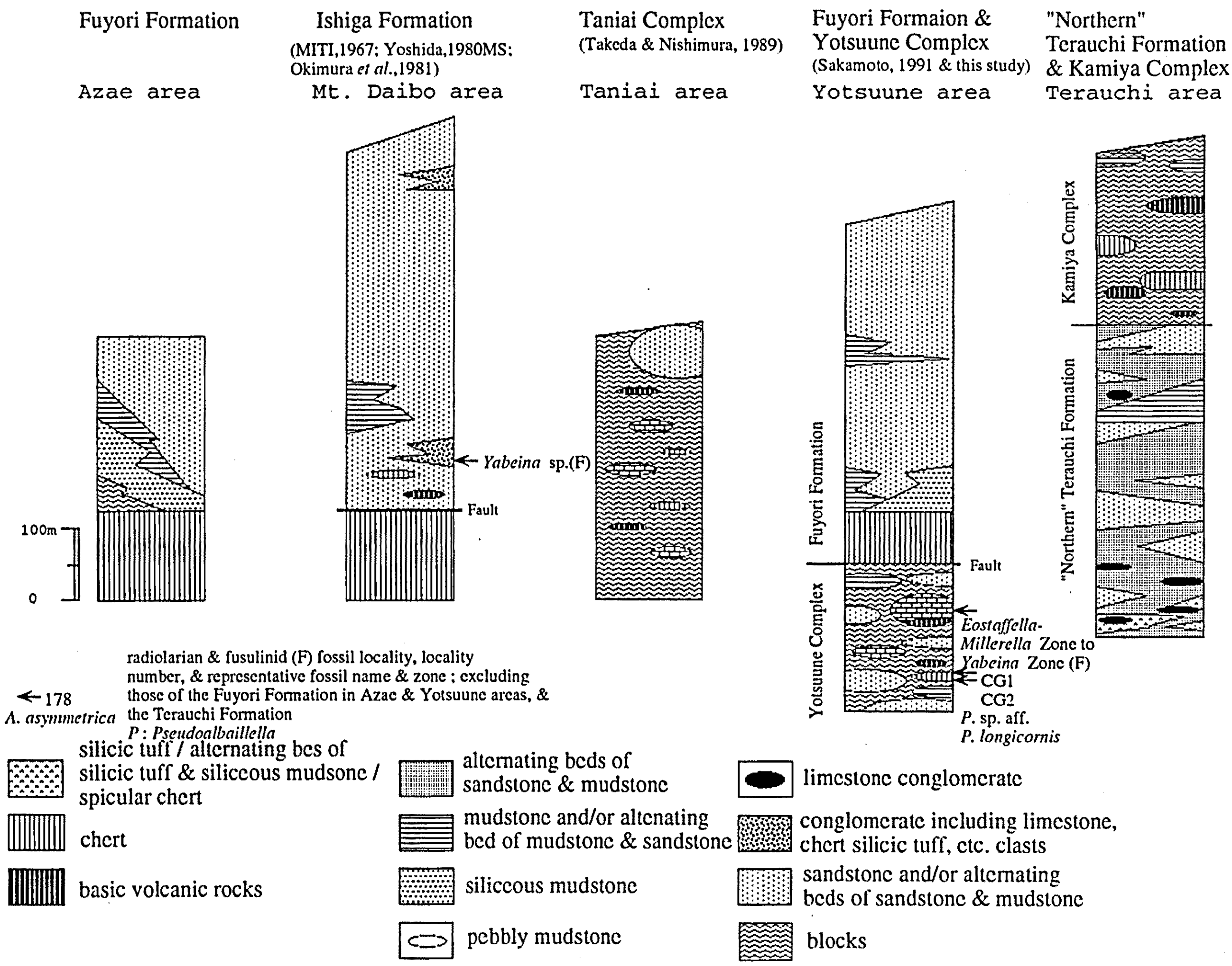


Fig. 21 : Generalized columnar sections of the Taniai, Yotsuune and Kamiya Complexes, and additionally Fuyori, Ishiga, and Terauchi Formations of each fault-bounded area in the Atetsu region.

formation) and the pumpellyite-chlorite zone (upper part of the formation).

The structure of the rocks in Ikura area was also described by Nishimura and Takeda (1989). The Taniai Complex with tectonically underlying the Oojaridani Formation and tectonically overlying the recrystallized and metamorphosed limestone and basic volcanics which are included the Atetsu Limestone together form a composite antiform consisting folds. These fold axes trend N 60°-65° E and axial planes are vertical. They have wavelength of 150 to 200 meters. These folds are referred as the Nappe boundary bending folds in this paper (see Chapter VI).

E. Kamiya Complex

(*Taniai Type* : newly proposed)

Name : The name derived from place, Kamiya, located in eastern Niimi City, Okayama Prefecture (Fig. 11).

Historical background : The complex has been previously included in a part of the Terauchi Formation (Sada, 1960, 1965; Otoh, 1987), but now independently treated as the Kamiya Complex by the author (Table 1).

Definition : The Kamiya Complex is characterized by a melange including various exotic blocks and it overlies the Terauchi Formation.

Stratotype : The holostratotype section is the road cutting from Terauchi to Kamiya, (upper half of B route, Fig. 13), Terauchi area.

Distribution : The complex is distributed in Kamiya and Terauchi, Terauchi area (Fig. 11).

Thickness : 200m+ in holostratotype section. The maximum thickness is estimated to be 250 meters (Fig. 13).

Description : The Kamiya Complex embeds exotic blocks of various sizes and lithologies with the matrix of siliceous mudstone and mudstone. Only large mappable blocks are shown in the geological map (Fig. 11).

Elongated large chert blocks occur in the west of Maki (350 x 120 square meters) and the west of Terauchi (500 x 50 square meters). The chert blocks are mostly massive, recrystallized, and various in color; white, light grey, and dark grey.

The blocks of basic volcanic rocks including metabasaltic rocks occur in several horizons, and the largest one attains to 100 x 20 square meters. The basic volcanic rocks are mostly massive, dark green to light green and rarely show lamination. The recrystallization and weak metamorphism erased the original texture and mineral composition. The metamorphic minerals; chlorite, prehnite, pumpellyite, albite, etc. can be observed under a microscope. The basic volcanic rocks more or less brecciated and are injected by siliceous and calcitic veins. The original rocks of the basic volcanic rocks are mostly inferred to have been basaltic tuffs.

The formation includes a lensic body of a massive mudstone. Some parts of the mudstone are calcareous.

No large limestone masses cannot be observed, but fine to medium-grained calcite grains occur in matrix of the melange.

Matrix of the melange is composed of diamictite (Flint *et al.*, 1960a, b) or pebbly mudstone. Diamictite is characterized by dispersion of poorly sorted, angular to subangular silt to pebble sized grains consisting of chert, basic volcanic rocks, siliceous mudstone, silicic tuff, in a sheared mudstone (mostly siliceous) matrix (Plate 8-5). Pebbly mudstone consists of relatively rounded clasts of mudstone, silicic tuff and sometimes basic volcanic rocks. The configuration of the clasts in a pebbly mudstone matrix is occasionally obscure. Beddings of the matrix are poorly developed, but in some outcrops show the stratification represented by intercalation of a thin layer of sandstone, lamination in a matrix, and the elongation axes of clasts nearly parallel to cleavage planes.

The lithologic features of the complex resemble those of the Taniai Complex, except for contain of metagabbroic and metagranitic rocks.

Structure : Two gentle intra-nappe folds are developed in the complex with NE-SW trends of axes (Fig. 11). The trace of the base of the complex shows a synform (Azae Synform; Figs. 11 and 12) slightly to moderately plunging to the W or NW.

Stratigraphic relationship : The exact contact between the Kamiya Complex and the underlying "Northern" Terauchi Formation is not clear. At the Loc. A of Fig, 11, for example, the relationship between the two cannot be decided whether conformable or fault contact. The Kamiya Complex, however, is presumed to conformably overly the "Northern" Terauchi Formation because of concordant structure and distribution of the both lithostratigraphic units as well as the underlying the Atetsu Limestone in a scale of geologic map (Figs. 11 and 12), even though the lithological change from the "Northern" Terauchi to Kamiya is abrupt.

Fossils : Poorly preserved siliceous sponge spicules and radiolarian fossils were recovered from the chert blocks and matrix of diamictite. The species are undetermined.

Remarks : Otoh (1987) described this formation as the upper part of the Terauchi Group. According to Otoh (1987), the formation consists of slump breccia and mudstone with subordinate silicic tuffs.

F. Yotsuune Complex

(*Taniai Type* : Kobayashi, 1950)

Name : The name was derived from Mt. Yotsuune, Yotsuune area, Hokubou Town, Okayama Prefecture (Fig. 3).

Historical background : The clastic formation fault-bounded to the Atetsu Limestone on the northern end in Yotsuune area was previously called as the Yotsuune Formation (Kobayashi, 1950) or Yotsuune Group (Yoshimura, 1961). According to Sakamoto (1991MS) and author's investigation, the Yotsuune Formation of Kobayashi's division can be divisible into two lithostratigraphic units, the lower and upper parts. The lower and upper parts are here referred as the Fuyori Formation and the Yotsuune Complex (Table 3).

Distribution : The complex is developed in Yotsuune area with ENE-WSW trend.

Thickness : Approximately 200 meters (Fig. 21).

Description : The complex is composed of melange suite including large elongated exotic blocks of limestone and basic volcanic rock (meter to kilometer order) in matrix of pebbly mudstone and mudstone. These blocks are mostly recrystallized and sheared. Sandstone, and alternating beds of sandstone and mudstone are also sporadically found and they are presumably embedded in matrix as blocks. These lithologic features resemble to those of the Taniai and Kamiya Complexes. However, the details in stratigraphy and age of the Yotsuune Complex are not yet clear.

Fossils : The limestone blocks associated with basic volcanics contain the Late Carboniferous to Middle Permian fusulinids, and they may have been probably derived from the Atetsu Limestone which appears to be similar in age and lithology (Sakamoto, 1991MS).

Stratigraphic relationship : The Yotsuune Complex thrusts over the metamorphic rocks of the Suo Terrane, and probably is in a fault contact with the Fuyori Formation. The complex has regional strikes from ENE to WSW and mostly dips to the north.

G. Atetsu Limestone

(Imamura, 1959; Sada, 1965)

Name : The name was derived from regional name, Atetsu Plateau, northwestern Okayama Prefecture.

The term of Atetsu Limestone is restricted to be used for limestones and basic volcanic rocks.

Northern and Southern Facies of the Atetsu Limestone (Fig. 22) : The Atetsu Limestone can be divided into two facies; Southern and Northern Facies (Tanabe, 1973MS; Okimura *et al.*, 1981). The Northern Facies of the Atetsu Limestone is represented by relatively well-developed stratification, especially seen in the lower limestones and basic volcanic rocks. Whereas the Southern Facies of the Atetsu Limestone is characterized by a massive light-grey limestone, with thin tuffaceous limestone intercalated in the lower part. Although the recognition of the two facies is sometimes difficult in field, especially for the upper part of the Atetsu Limestone, microscopic investigation of lithofacies makes the recognition usually possible.

Description : The Atetsu Limestone is divided into five formations, the Lower Carboniferous Nagoe, the Upper Carboniferous Kodani, the Lower Permian Iwamoto, the lower Middle Permian Shoyama, and the middle Middle Permian Maki Formations (Imamura, 1959; Sada, 1965; Figs. 5 and 22).

i) Nagoe Formation (Okimura, 1958; Sada, 1965)

The Nagoe Formation typically crops out along the road cutting from Morikuni to Nagoe, located in eastern Niimi City (Okimura, 1958; Fig. 18). The formation is also distributed in several areas in the Atetsu region. The maximum thickness of the formation attains to 350 meters around Nagoe area (Sada, 1965), but the thicknesses generally do not exceed 150 meters.

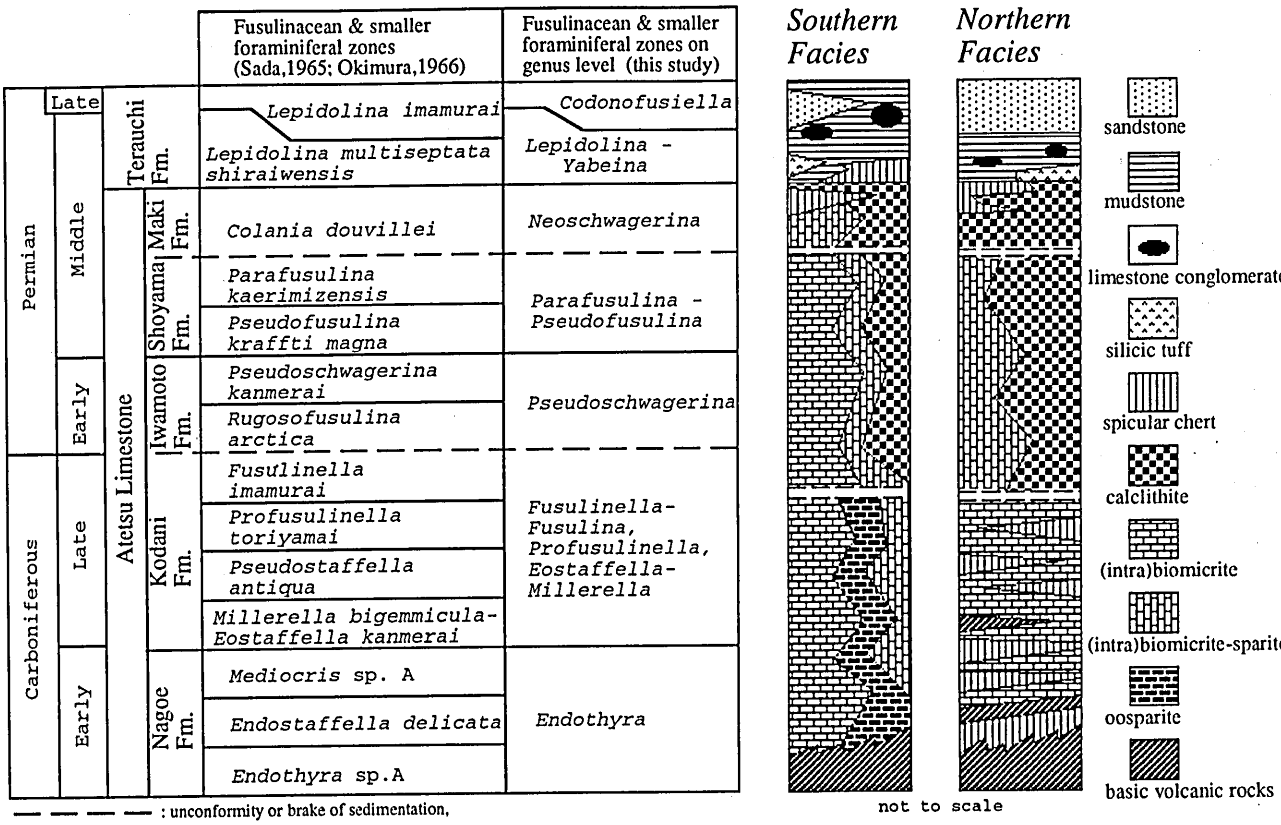


Fig. 22 : Generalized columnar sections showing lithofacies of Northern and Southern Facies of Atetsu Limestone and Terauchi Formation. Compiled from Sada (1965), Okimura (1966), Tanabe (1973MS), Nishidani (1985MS), Sakamoto (1991MS), and this study. Fusulinacean and smaller foraminiferal zones by previous works and by the author are also listed.

The formation mainly consists of dark green basaltic tuff, tuff breccia, and lava, and dark red to dark green basic tuffaceous limestone. Sponge spicular chert, white to light grey colored, is intercalated with tuffaceous limestone in several areas.

Lower Carboniferous smaller foraminifera and conodont biostratigraphy have been studied in the formation (Okimura, 1958; Koike, 1967).

ii) Kodani Formation (Okimura, 1958; Sada, 1965)

The Kodani Formation is most extensively developed in Kodani, located in the eastern Atetsu region, and widely distributed in Azae, Dobashi and other areas. In Fig. 3, the Nagoe and Kodani Formation are collectively shown as the Carboniferous Atetsu Limestone, but the distributing areas mostly expose the Kodani Formation. The thickness of the formation ranges from 60 to 350 meters.

The Northern Facies of the formation consists of micritic limestone frequently intercalated spicular chert ranging from several centimeters to 1 meter thick. Stratifications of the limestone are commonly found. In contrast, the Southern Facies of the formation is remarkably intercalated with massive oosparite (Fig. 22).

The Upper Carboniferous smaller foraminifers and conodont biostratigraphy have been studied in the formation (Okimura, 1958; Koike, 1967).

iii) Iwamoto Formation (Imamura, 1959; Sada, 1965)

The formation is thickest and most widely distributed among the formations of the Atetsu Limestone in the Atetsu region. The thickness of the formation is estimated to be around 200 meters.

The formation mainly consists of light grey "massive" limestone and calclithite (limestone breccia). But "massive" limestone is more or less brecciated with a matrix filled with sparry calcite under a microscope. Calclithite, especially dominant of the Northern Facies, contains various sized limestone clasts with various lithofacies derived from underlying formations. These two limestone facies can be correlated to the broken limestone and the type A limestone breccia, respectively, of the Akiyoshi Limestone Group described by Sano and Kanmera (1991a).

Lack of the fusulinid faunal interval can be recognized between Kodani and Iwamoto Formations (Imamura, 1969; Sada, 1965).

iv) Shoyama Formation (Imamura, 1959; Sada, 1965)

The Shoyama Formation occurs in relatively limited area in the Atetsu region. The maximum thickness is estimated to be 125 meters (Sada, 1965). The geologic maps (Figs. 11, 16 and 18) show distributions of the Iwamoto and Shoyama Formations collectively.

The formation consists of "massive" light grey sparitic limestone.

v) Maki Formation (Imamura, 1959; Nogami, 1962; Sada, 1965)

The Maki Formation typically crops out in Maki and Yukawa, in Terauchi area (Fig. 13). The thickness of the formation in Maki and Yukawa is more than 100 meters.

The formation is characterized by dark grey to light grey calclithite (limestone breccia and/or conglomeratic limestone). Thin sponge spicular chert is intercalated in calclithite in Futatsugi, Terauchi area. The limestone clasts in the calclithite are angular to subangular, poorly sorted, densely packed, and various in size, age, and lithology, and are packed with a small amount of a sparry or muddy matrix. The calclithite of the formation can be distinguished from that of the Iwamoto Formation by having muddy matrix, its age and color. The calclithite of the formation may correspond to the Type B limestone breccia by Sano and Kanmera (1991a).

The discontinuities of the fusulinacean zones have been recognized between the underlying formation and the Maki Formation (Imamura, 1959; Sada, 1960, 1965).

Remarks : Many stratigraphical and paleontological studies have been done for the Atetsu Limestone (see Chapter III).

V. Radiolarian biostratigraphy

The radiolarian biostratigraphies of the Carboniferous to Permian rocks in the Atetsu region are described in this Chapter.

Thirteen radiolarian zones from the Late Carboniferous to Late Permian have been constructed from continuous sequences of the bedded chert, which are included as several exotic blocks in a Jurassic accretionary complex of the Tamba Terrane (e.g. Ishiga, 1986b, 1990b). Recently, Ishiga (1991) redefined the Middle to Late Permian radiolarian zones, thus fourteen radiolarian zones from the Late Carboniferous to Late Permian can be recognized.

Rock samples for extracting radiolarians were collected from fine grained siliceous and terrigenous clastic rocks, such as chert, silicic tuff, siliceous mudstone, mudstone, and mudstone part of alternating beds of mudstone and sandstone. Samples are broken into small fragments, or were cut into cubes about 10x10x5 cm^3 in the laboratory, and dip into a plastic beaker (500 or 1000 milliliters) with 5 to 10 % hydrofluoric solution for 10 to 24 hours. Subsequently, the residue was gathered by using #200 sieve, and radiolarian remains were picked up from the residue with a fine brush under a binocular microscope. Several samples were treated for twice or more. Scanning electron microscope (SEM) photographs were taken and the species were identified and measured.

A. Morphological difference of *Follicucullus*

Follicucullus Ormiston and Babcock is an important index fossil of the late Middle to early Late Permian time from its rather short range of occurrence. Among several species of this genus, however, a determination of it is sometimes very difficult and requires careful observation. *Follicucullus* occurs from not only the rocks in the Atetsu region but also from the other regions of the other Akiyoshi Terrane rocks. Thus, the morphological differences of several species of *Follicucullus* from the Akiyoshi Terrane rocks are described here.

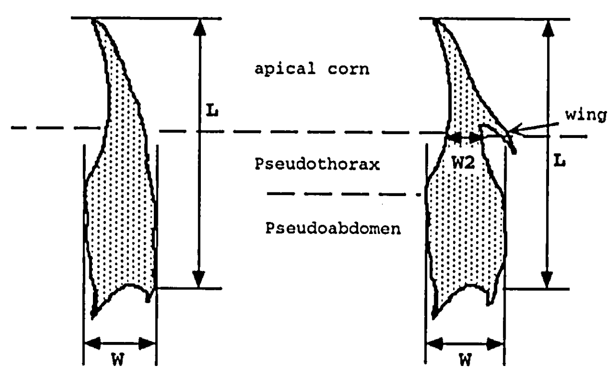


Fig. 23: Sketches of *Follicucullus scholasticus* Ormiston and Babcock and *F. japonicus* Ishiga (after Ishiga, 1991), and *F. monacanthus* Ishiga and Imoto showing terminology and measured features. A discrimination by pseudothorax and pseudoabdomen of the former two species is very difficult. Abbreviations: W, width of pseudothorax; L, length of shell, W2, width of shell under proximal part of wing.

Follicucullus is characterized by conical shell consisting of apical cone, psudothorax and pseudoabdomen (see terminology in Fig. 23), and it was distinguished into six species listed below; *Follicucullus scholasticus* Ormiston and Babcock, *F. ventricosus* Ormiston and Babcock, *F. monacanthus* Ishiga and Imoto, *F. japonicus* Ishiga, *F. charveti* Caridroit and De Wever, *F. bipartitus* Caridroit and De Wever. Morphological differences of species of *Follicucullus* were already discussed by Ishiga (1984, 1991). According to him, the species of *Follicucullus* are identified by characteristics of the shell construction summarizing as follows:

1. possession of wing at apical cone = *F. monacanthus*
2. inflation of pseudothorax and having groove = *F. ventricosus*
3. elongated conical shell
   a. conical shell without inflation = *F. scholasticus*
   b. undulated shell and inflation of pseudothorax = *F. japonicus*

According to Ishiga (1991), the proportion of shell represented by the ratio W/L (where W is the width of pseudothorax and L is the length of shell, see Fig. 23) is useful attempt of the differentiation of *F. scholasticus* and *F. japonicus*. Fig. 24 shows the W/L ratio diagrams based on the measurement values of shell features including *Follicucullus* which occur from the Terauchi and Fuyori Formations in the Atetsu region.

On the scanning electron microscope observation, *F. monacanthus* can be usually distinguished from the other species of *Follicucullus* by having wing. However, shell form of the most specimens of *F.* sp. cf. *F. japonicus* described in the paper from the Atetsu region closely resembles to that of *F. monacanthus* except for lack of the wing (see Plate 1 -3,4,6; Plate 2-7,12; Plate 3-1). On Fig. 24, the discrimination between *F. monacanthus* and *F.* sp. cf. *F. japonicus* is difficult by the W/L ratio. On the other hand, *F.* sp. cf. *F. japonicus* from the Atetsu region differs from *F. japonicus* from the Tamba Terrane in having stronger undulation. If the "wing" of *F.* sp. cf. *F. japonicus* from Atetsu was not the one destroyed by any reasons, these specimens probably indicate the intermediate forms between *F. monacanthus* and *F. japonicus.*

F. japonicus and *F.* sp. cf. *F. japonicus* from the Atetsu region are clearly distinguished from *F. scholasticus* from the Nishiki region (Fig. 24). However, some of them are bigger in size than those of the Muikaichi specimens (Fig. 24). *F.* sp. cf. *F. scholasticus* from the Atetsu region (Plate 1 -5) have a weak undulation on shell, but its W/L ratios are closely resemble to that of *F. scholasticus* from the Muikaichi specimens except for shell length.

In summary, on the basis of morphological differences, *Follicucullus* from the Atetsu region can be distinguished as follows: *F. japonicus*, *F.* sp. cf. *F. japonicus*, *F. monacanthus*, *F.* sp. cf. *F. scholasticus.*

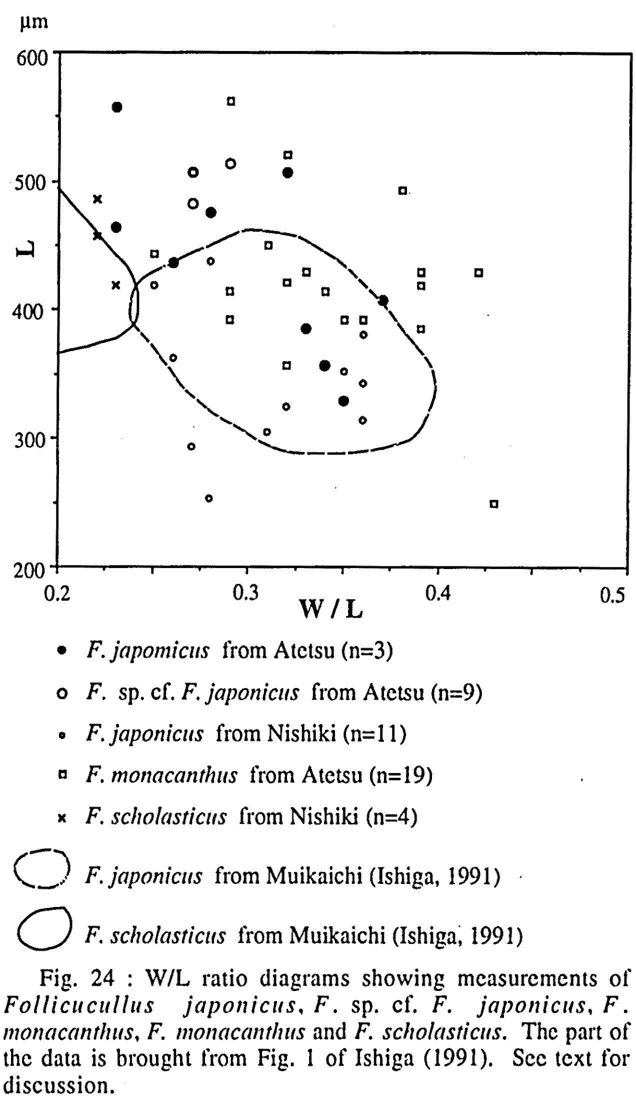


Fig. 24 : W/L ratio diagrams showing measurements of *Follicucullus japonicus*, *F.* sp. cf. *F. japonicus*, *F. monacanthus*, *F. monacanthus* and *F. scholasticus*. The part of the data is brought from Fig. 1 of Ishiga (1991). See text for discussion.

B. Radiolarian assemblages and zones in the Atetsu region

The Permian radiolarian fossils were recovered from the Terauchi and Fuyori Formations, and Yotsuune Complex in the Atetsu region by the author and previous workers. The Late Carboniferous conodont fossils were also found from the Fuyori Formation (Otoh, 1987). No well preserved radiolarian and conodont fossils have so far reported been from the Ishiga Formation, and Taniai and Kamiya Complexes.

1. "Northern" Terauchi Formation

Both the "Northern" and "Southern" Terauchi Formation yields the middle Middle Permian to early Late Permian radiolarian assemblages. The radiolarians were found from silicic tuff, spicular chert, alternating beds of silicic tuff and mudstone, mudstone, and mudstone part of alternating beds of sandstone and mudstone. They are relatively well preserved.

List of characteristic radiolarian species of the "Northern" Terauchi Formation is shown in Fig. 25. Localities of samples are shown in Figs. 11 and 14. Refer to the sampled horizons on lithostratigraphic columnar sections in Figs. 13 and 26.

a. Lower Member of the "Northern" Terauchi Formation

The lowermost horizon represented by silicic tuff or spicular chert and alternating beds of silicic tuff and mudstone (Locs. 431A and 511) of the Lower Member of the "Northern" Terauchi Formation yields *Pseudoalbaillella* sp. cf. *P. fusiformis* ?, *P.* sp. aff. *P. longicornis,* and spherical polycystines (Fig. 25). Yamashita and Ishiga (1990) reported radiolarian fossils from six samples of one locality (Loc. YI in Fig. 11) of silicic tuff of the "Northern" Terauchi Formation. Their sampled horizons are shown in Fig. 26, and are included in the lowermost horizon of the member in this paper. The radiolarian fossils reported by them are composed of *Follicucullus monacanthus*, *F.* sp., *P.* sp. cf. *P. fusiformis*, *P.* sp. cf. *P. yanaharensis*, and *P.* sp. Mudstone of the middle part of the member (Loc. 392) yields *F. monacanthus* and *F.* sp. cf. *F. japonicus*.

P. fusiformis has a relatively long range, but it commonly occurs in *Pseudoalbaillella globosa* Zone (Ishiga, 1986b; Nishimura K., 1990). According to Yamashita and Ishiga (1990), however, *P.* sp. cf. *P. fusiformis* occurs with *F. monacanthus* from the same sample. Thus, its range probably extends longer in the Atetsu region than in the Tamba Terrane. *F. monacanthus* is a diagnostic species of the *F. monacanthus* Zone (see Ishiga, 1986b, 1990b), and the base of this zone is defined by the first occurrence of *F. monacanthus* (Ishiga, 1991).

F. japonicus has a relatively long range, but its first occurrence marks the base of the *F. japonicus* Zone (Ishiga, 1991). The morphologic characteristics of *F.* sp. cf. *F. japonicus* in the Atetsu region suggest connection of *F. monacanthus* and *F. japonicus.* Thus, the first occurrence of *F.* sp. cf. *F. japonicus* in the Atetsu region dose not directly corresponds to the base of *F. japonicus* Zone. The phylogenetic position of *F.* sp. cf. *F. japonicus* is probably located between *F. monacanthus* and *F. japonicus.* If it is the case, the horizon of the first occurrence of this species is correlated to a horizon within the *F. monacanthus* Zone. In this paper, the assemblage characterizing the presence of *F.* sp. cf. *F. japonicus* is named tentatively *F.* sp. cf. *F. japonicus* Assemblage, the horizon of it called *F.* sp. cf. *F. japonicus* Zone.

In summary, the Lower Member of the "Northern" Terauchi Formation includes the *F. monacanthus* Zone and

Formation and areas	"Northern" Terauchi Fm.							"Southern" Terauchi Fm.							Maedani Fm.	
	Terauchi						Hiroso	Ku.	Azae		Arasako			No.	Tojo	
Localities	47	168	392	406	431A	511	1375	1337	936A	1396	AC1	AC3	AC4	NC1**	T10G	T10H
Radiolarians / Lithologies	ms/ss	ms	ms/ss	ms/ss	tf	ms/tf	ms	ms	tf/ms	tf	ch	ch	ch	ch	tf	tf/ms
Follicucullus sp. cf. *F. scholasticus* O & B		•			?											
F. sp. cf. *F. japonicus* Ishiga	⬤*		⬤	•			•	•		•					?	
F. monacanthus Ishiga & Imoto	⬤		•					●		⬤	⬤				•	
F. sp.	•	•							•		•				•	
Pseudoalbaillella globosa Ishiga & Imoto												●	•			
P. sp. cf. *P. fusiformis* (Holdworth & Jones)					•	•		•		•	?	•	•		•	
P. yanaharensis Nishimura & Ishiga					?					•			●		•	
P. sp. aff. *P. longtanensis* Sheng & Wang													?			
P. sp. cf. *P. aidensis* Nishimura & Ishiga												?				
P. sp. aff. *P. longicornis* Ishiga & Imoto	•	•			•	•	•	•		⬤		●	⬤	•		
P. sp.	•													•	•	•

Number of specimens after more than twice of 24 hours treatments by useing 5 to 10 % hydrofluoric solution : ⬤ > 5, ● 3 - 5, • < 3

Fig. 25 : Occurrences of the radiolarians from the Terauchi and Maedani Formations. Localities of samples are shown in Figs. 11, 14, 15, and 29.

Abbreviations : ?: affinity, * : including two specimens of *F. japonicus* var. B by Ishiga (1991), ** : after Sakamoto (1991MS), Ku. : Kurauchi, No. : Nomiya, Fm. : Formation, ms : mudstone, ms/ss : alternating beds of mudstone and sandstone, tf : silicic tuff, ms/tf : alternating beds of silicic tuff and siliceous mudstone, ch : sponge spicular chert, O & B : Ormiston and Babcock

the lower part of the *F.* sp. cf. *F. japonicus* Zone (refer to Fig. 27). The boundary between the two zones is situated between horizons of Locs. 511 and 392.

b. Upper Member of the "Northern" Terauchi Formation

Two samples (Locs. 47 and 406) from mudstone layers of the alternating beds of mudstone and sandstone of the lower horizons in this member is characterized by the occurrence of *F. monacanthus* and *F.* sp. cf. *F. japonicus*. Whereas, mudstone (Loc. 168) of the middle horizon yields *F.* sp. cf. *F. scholasticus* but lacks of *F. monacanthus* and *F. japonicus*. The range of *F. scholasticus* is restricted in upper part of *F. japonicus* Zone to *F. charveti* Zone by Ishiga's zonation. *F.* sp. cf. *F. scholasticus* reported in this paper somewhat differs from *F. scholasticus* reported in other regions by having a weak undulation.

Judging from occurrence above three species, the Upper Member includes the *F.* sp. cf. *F. japonicus* Zone. On the basis of the range chart of the characteristic species by Ishiga (1986b, 1991), the upper part of the member may correspond to upper part of the *F. japonicus* Zone.

2. "Southern" Terauchi Formation

The Middle to Late Permian radiolarians occur in spicular chert, silicic tuff and mudstone in three sections of Arasako, Azae and Kurauchi. List of characteristic radiolarian species of the 'Southern" Terauchi Formation is shown in Fig. 25. Localities of samples are shown in Figs. 15 and 18. Refer to the sampled horizons on lithostratigraphic columnar sections in Figs. 15 and 26.

In Arasako section, the holostratotype of the "Southern" Terauchi Formation, a spicular chert (Locs. AC-3 and AC-4) of the lowermost horizon of the formation yields abundant sponge spicules and radiolarians, such as *P. globosa*, *P.* sp. cf. *P. fusiformis*, *P. yanaharensis*, *P.* sp. aff. *P. longicornis*, stauraxon polycystines and spherical polycystines. *P. yanaharensis* was first reported from the Maizuru Group, Maizuru Terrane, and occurs together with *P. fusiformis*, *P. globosa* and *F. monacanthus* (Nishimura and Ishiga, 1987). This assemblage is characterized by occurrence of *P. globosa* and by absence of *F. monacanthus* and *F. japonicus*.

According to Ishiga (1986b), the base of *P. globosa* Zone is marked by the first occurrence of *P. globosa*, while the top of this zone corresponds to the first occurrence of *F. monacanthus*. Thus, the radiolarian assemblages of Loc. AC-4 and AC-5 are clearly correspond to the *P. globosa* Zone.

Whereas the top of spicular chert (Loc. AC-1) in Arasako section and silicic tuff in Azae section (Loc. 1396) are characterized by the occurrence of well preserved *F. monacanthus*. Mudstone (Loc. 1337) of the upper part of the formation in Kurauchi section contains *F. monacanthus* and *F.* sp. cf. *F. japonicus*.

From these occurrences, the "Southern" Terauchi Formation includes the *P. globosa* Zone and *F. monacanthus* Zone in the lower part, and *F.* sp. cf. *F. japonicus* Zone in the upper part. The boundaries among the above three zones are defined by the two horizons between Locs. AC-3 and AC-1, and Locs. 1396 and 1337, respectively.

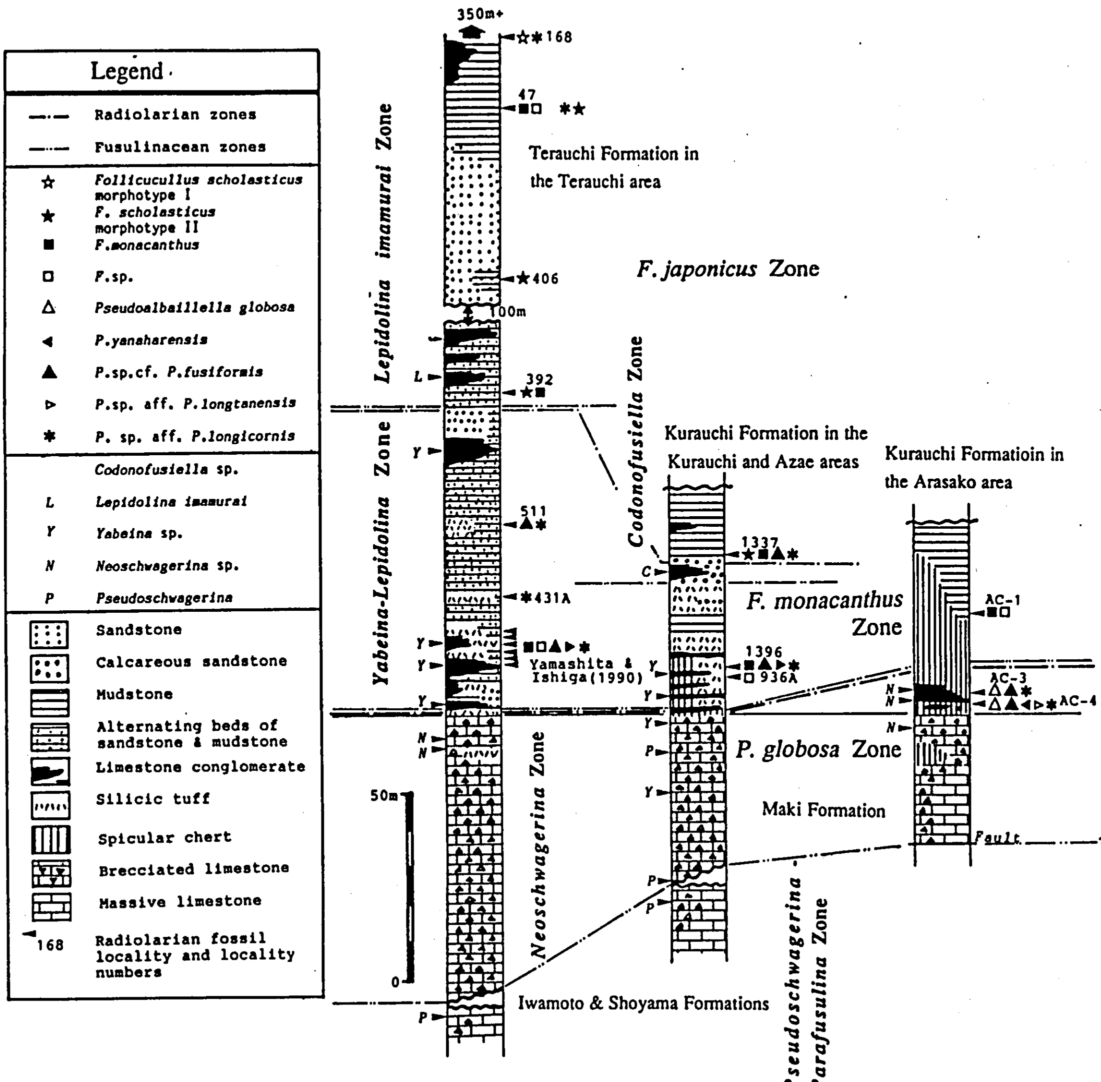


Fig. 26 : Generalized columnar sections of the Terauchi Formation showing sampled horizons of the radiolarian and fusulinid fossils (after Naka and Sakamoto, 1992). The radiolarian and fusulinacean zones are also shown. See text for discussion. *F. scholasticus* morphotype I and *F. scholasticus* m. II should be *F. scholasticus* and *F.* sp. cf. *F. japonicus*, respectively. F. japonicus Zone should be *F.* sp. cf. *F. japonicus* Zone. The Kurauchi Formation should be "Southern" Terauchi Formation.

3. Fuyori Formation

The chert of the lower part of the Fuyori Formation yields abundant radiolarians and siliceous sponge spicules, but they are generally poorly preserved. Otoh (1987) reported conodont fossils, *Idiognathoides sinuatus* and *Gondolella clarki* from the chert in Ogyou (Fig. 3). These two species indicate the Morrowan to Atokan, Late Carboniferous. While the chert in Azae area yields radiolarian fossils, *Pseudoalbaillella* sp. aff. *P. longicornis*. This species has a long range, but restricted in the Middle Permian time (Ishiga, 1986b). Thus, the lower chert succession includes the Lower Carboniferous to Middle Permian, although the Early Permian fossils have not been found yet.

The radiolarians of the siliceous mudstone and mudstone of the middle part are mostly poor-preserved. However, they are identified as *Follicucullus monacanthus*, *F. scholasticus* (Otoh, 1987; this species should be changed to *F. japonicus* because *F. japonicus* regarded as *F. scholasticus* morphotype II before Ishiga, 1991), *P.* sp. cf. *P. fusiformis*, *Albaillella asymmetrica*, etc. *A. asymmetrica* has a long range, but commonly occur from the *A. sinuata* Zone and above the *P. longtanensis* Zone (Ishiga, 1986b). Judging from the assemblage, the middle mudstones succession includes radiolarian zones as follows; the *A. sinuata* Zone - *P. globosa* Zone ?, *F. monacanthus* Zone and *F. japonicus* Zone. It is noteworthy that siliceous mudstones of the eastern Atetsu region tend to including older radiolarian zone than that of the western one (Figs. 20 and 28).

No radiolarian fossils have been found in the upper sandstone.

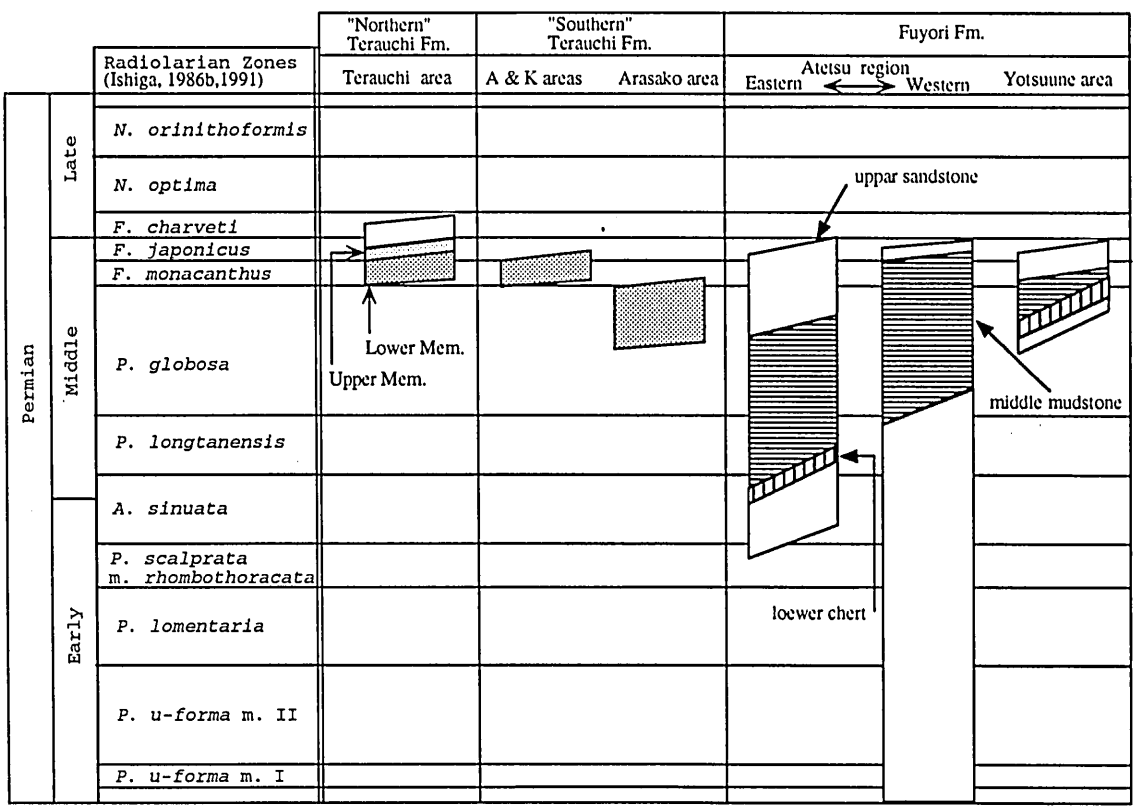
4. Yotsuune Complex

Two lenticular chert conglomerates, which composed of abundant sub-angular to rounded chert clasts in slightly siliceous mudstone matrix, of the Yotsuune Complex yields *P.* sp. aff. *P. longicornis* and *P.* sp. (Sakamoto 1991MS). These radiolarian assemblages are not enough to determine the radiolarian Zone, but occurrence of *P.* sp. aff. *P. longicornis* restricted in the Middle Permian.

Formation and areas	Fuyori Fm.																			Yotsuune Com.	
	Sakamoto		Mt.Tenjin		Mochidani						Kusama	Azae			Ogyo	Mt. Yotsuune						
Localities	59	327A	324T	11*	152	161	626	6*	MS1**	MS2**	KS1**	178	944	AZ-A	8*	YC1**	YS1**	YS2**	YS4**	YS5**	CG1**	CG2**
Radiolarians / Lithologies	ms	ms	ms/tf	ms	ms/ss	tf	ms	ms	s. ms	s. ms	s. ms	s. ms	s. ms	ch	ch	ch	s. ms	s. ms	s. ms	s. ms	ch cgl.	ch cgl.
Follicucullus scholasticus Ormiston & Babcock				◆ ##																		
F. monacanthus Ishiga & Imoto			•	◆												?						
F. sp.		•#								◆								?				
P. sp. cf. *P. fusiformis* (Holdworth & Jones)	•			◆																		
P. sp. aff. *P. longicornis* Ishiga & Imoto	•			◆	•	⬤	•	◆	◆	◆		•	•				◆				◆	◆
P. sp.									◆	◆		•		•			◆	◆	◆	◆	◆	◆
Albaillella asymmetrica Ishiga & Imoto											?	⬤										
Conodonts: *Gondolella clarki* Koike															◆							
Conodonts: *Idiognathoides sinuatus* Gunnell															◆							

Number of specimens after more than twice of 24 hours treatents by using 5 to 10 % hydrofluoric solution : ⬤ > 5, ● 3 - 5, • < 3, ◆ number of specimens unknown.

Fig. 27 : Occurrences of the radiolarians from the Fuyori Formation and the Yotsuune Complex. Localities of samples are shown in Figs. 16, 18, and 19.
Abbreviations : ?: confer, # : including *F.* sp. cf. *F. japonicus* ?, ## : See text for discussion, * : after Otoh (1987), ** : after Sakamoto (1991MS), Fm. : Formation, Com. : Complex, ms : mudstone, s.ms. : siliceous mudstone, ms/tf : alternating beds of silicic tuff and siliceous mudstone, ch cgl.: conglomerate composed of abundant sub-angular to rounded chert clasts in siliceous mudstone matrix



Abbreviations: Carbon., Carboniferous; Fm., Formation; Mem., Member; A & K, Azae and Krauchi; *N., Neoalbaillella; F., Follicucullus; P., Pseudoalbaillella; A., Albaillella*

Fig. 28 : Diagram showing the radiolarian zones of the Terauchi and Fuyori Formations. Unhatched areas in columns show the parts lacking radiolarian occurrence.

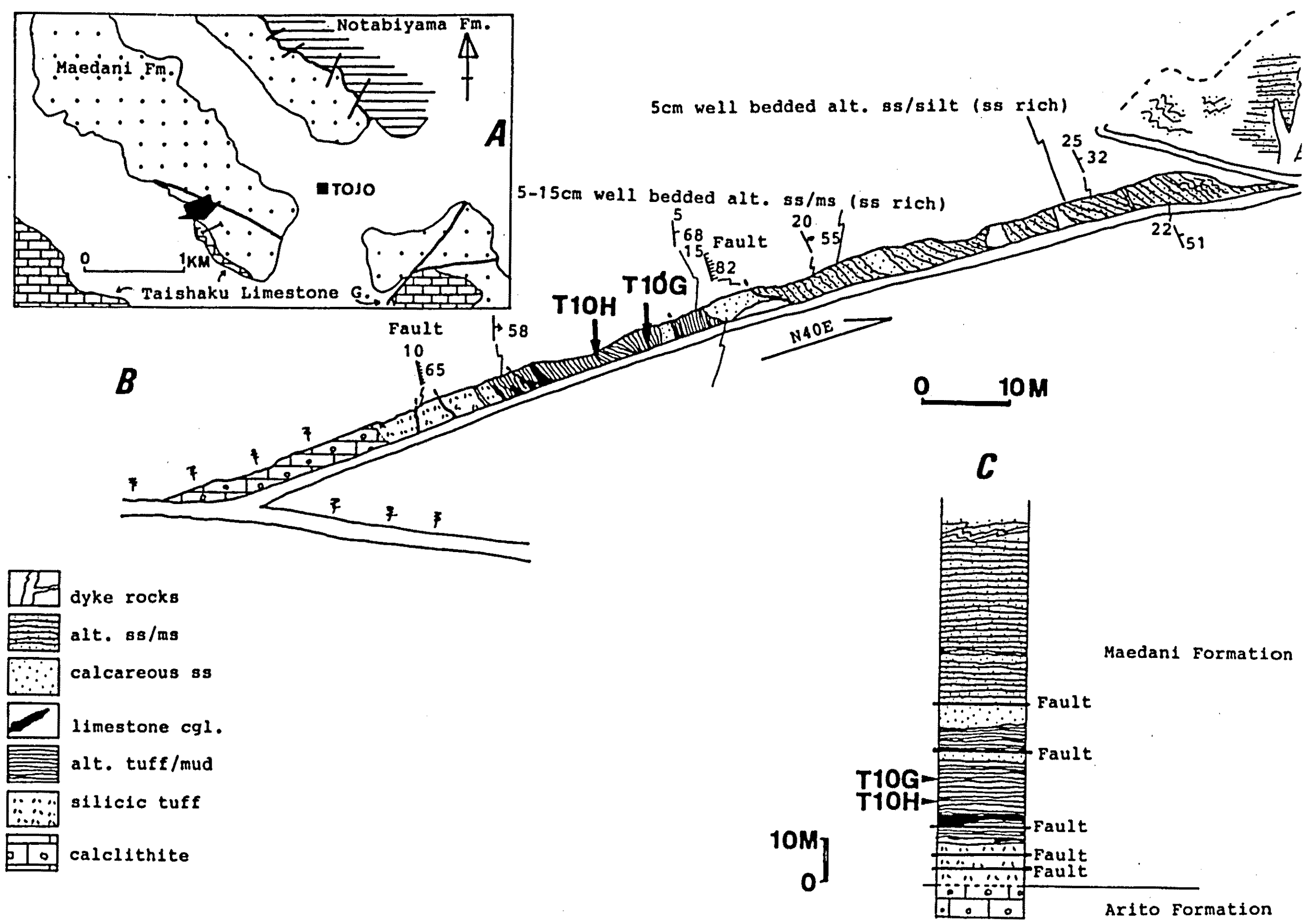


Fig. 29 : A; Index map showing examined route (arrow). B; A route map showing radiolarian fossil localities (T10H and T10G). A route map also includes the conformable contact between the Arito Formation (Taishaku Limestone) and the overlying Maedani Formation. C; A columnar section of the route mapped area showing the sampled horizons.
Abbreviations : alt. ss/ms : alternating beds of sandstone and mudstone, ss : sandstone, cgl. : conglomerate, alt. tuff/mud : alternating beds of silicic tuff and siliceous mudstone, alt. ss/silt : alternating beds of sandstone and siltstone

C. Radiolarian assemblage of the other regions

Reexamination was done on the 1) correlation between the radiolarian and fusulinacean biostratigraphy, 2) age of the boundary between the siliceous rocks (mainly radiolarian chert) and overlying terrigenous clastic rocks in the Akiyoshi Terrane, 3) determination of the Carboniferous and Permian boundary by the radiolarian biostratigraphy in the Akiyoshi Terrane. Radiolarian fossils from the Maizuru and Ultra-Tamba Terranes in the south of Oga region are also reported here.

1. Radiolarian assemblage of the Maedani Formation in the Taishaku region: for reexamination of 1)

The Maedani Formation, which conformably overlies the Marginal Facies of the Taishaku Limestone (Hase *et al.*, 1974), is composed of alternating beds of sandstone and mudstone, and sandstone. No radiolarian fossils had been reported by previous workers.

However, the Middle Permian radiolarian fossils were found from the alternating beds of silicic tuff and mudstone, which represents the lowermost horizon of the formation, near Tojo, Taishaku region . Localities of the radiolarian-bearing two samples (T10H and T10G) are shown in Figs. 2 and 29. Fig. 29 shows the route map and columnar section including the boundary between the underlying Taishaku Limestone (Arito Formation) and Maedani Formation, respectively. Sample T10H contains radiolarian fossils as follows: *Follicucullus monacanthus*, *F.* sp. cf. *F. japonicus* ?, *Pseudoalbaillella yanaharensis*, *P.* sp. cf. *P. fusiformis*, etc. (Fig. 25 and Plate 2). The co-occurrences of *P. yanaharensis*, *P. fusiformis*, *P. globosa* and *F. monacanthus* also reported from a sample in the Maizuru Group, Maizuru Terrane (Nishimura and Ishiga, 1987). In the Tamba Terrane, *F. monacanthus* and *P. fusiformis* do not co-occur.

From the occurrence of *F. monacanthus* in the assemblage and the comparable assemblage with one in the Maizuru Group, the assemblage possibly directly corresponds to the *F. monacanthus* Zone. Thus, the lowermost horizon of the Maedani Formation includes the *F. monacanthus* Zone.

2. Radiolarian assemblage around the boundary between the siliceous rocks and overlying terrigenous clastic rocks in the Yoshii Group, Yoshii area: for reexamination of 2)

The Yoshii Group in the Yoshii area comprises radiolarian chert, siliceous mudstone, and sandstone and shale in ascending order (Sano *et al.*, 1987). The gradual lithologic change from chert to overlying siliceous mudstone can be observed in the YS1 outcrop which is a

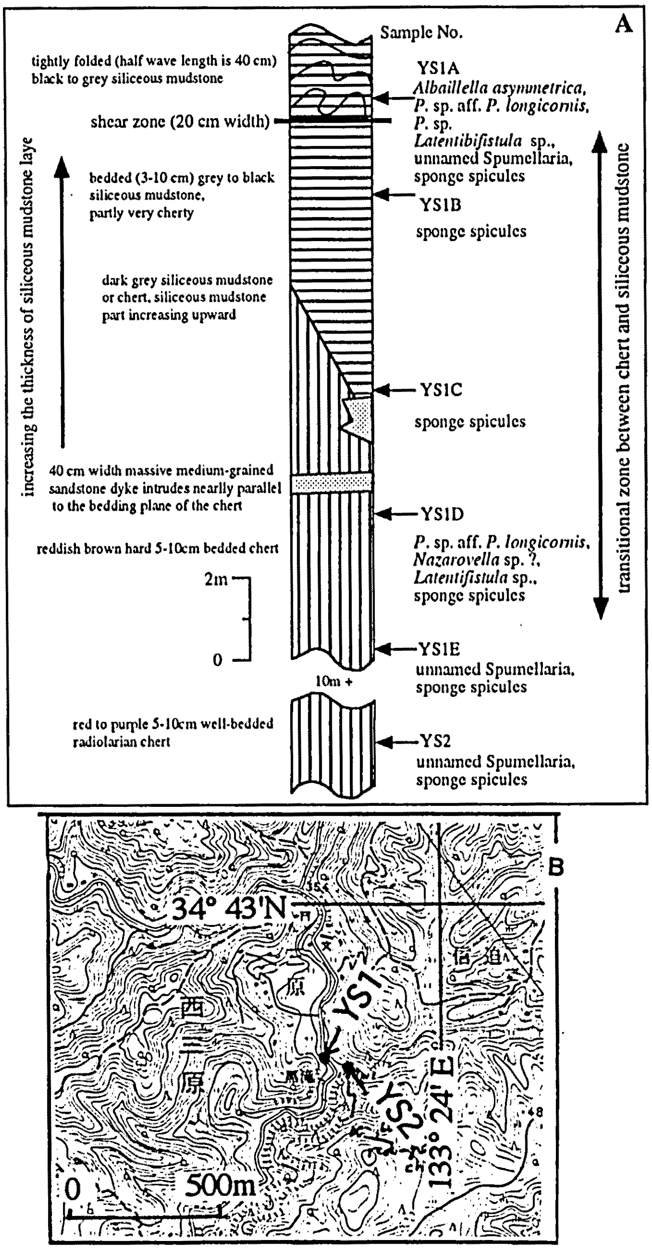


Fig. 30 : A; A columnar section including the transitional zone between chert and siliceous mudstone of YS1 and YS2 outcrops. Sample horizons of radiolarian fossils and thin sections are shown. Radiolarian species names of each sample are also shown. Refer to Plate 5. B; A map showing the localities of YS1 and YS2 outcrops. The topographic map is a part of "Jito" on 1/25,000 scale by Geographical Survey Institute of Japan.

new cutting for construction of a road (Fig. 30 -B). Fig. 30 -A shows the columnar section including transition zone between chert and siliceous mudstone at YS1. It is noteworthy that an outcrop showing the transition zone between two lithologies had never been found on outcrop order in the Akiyoshi Terrane.

Abundant radiolarian fossils yield from four samples in the YS1 and YS2 outcrops (Fig. 30). They are, however, poor in preservation. The chert layer contains *Pseudoalbaillella*. sp. aff. *P. longicornis*, etc. and the overlying siliceous mudstone contains *Albaillella asymmetrica*, *P.* sp. aff. *P. longicornis* (Fig. 30 and Plate 5) The two identified to the species level have a long range, but co-occurrence of the two species is restricted in the *P. longtanensis* and *P. globosa* Zone (Ishiga, 1986b). Thus, the transition zone between chert and siliceous mudstone is located in an interval of the two zones.

Sada *et al.* (1985) and Sano *et al.* (1987) reported that radiolarian and conodont fossils from the Yoshii Group in the Yoshii area. According to Sano *et al.* (1987), the boundary between chert and siliceous mudstone is placed at boundary between *P. longtanensis* Zone and *P. globosa* Zone from composite columnar section. The author's data are consistent with that of Sano *et al.* (1987).

3. Radiolarian and conodont assemblages of chert in the Yoshii Group, Yuki area: for reexamination of 3)

Chert layers in Chikada, Yuki area, approximately 200 meters in thickness, yield the Late Carboniferous conodont fossils (Oho *et al.*, 1985; Sada *et al.*, 1985), and that are considered as equivalents to the Yoshii Group (see Chapter II). According to Oho *et al.* (1985), two localities (Y82050, and Y82051, Fig. 31 -A) yield the Late Carboniferous conodonts, such as *Idiognathoides* cf. *convexus*, *Ozarkodina* cf. *orientale*, *Gondolella* sp., *Hindeodella* sp. (from Y82050), *Streptognathodus* sp., and *Hindeodus* sp. (Y82051). The Late Carboniferous conodonts and radiolarians from chert are rarely found in the Akiyoshi Terrane (the occurrences are reported from three areas: Yuki area; Taishaku region, Goto, 1988; Atetsu region, Otoh, 1987).

The Middle Permian radiolarian fossils and poor-preserved conodont fossils occur from chert in the same localities, Y82050 and Y82051 of Oho *et al.* (1985). Figs. 31-B and 31-C show the sampled horizons on columnar sections of the examined outcrops. The vertical distribution of radiolarian and conodonts fossils is also shown in Figs. 31 -B and 31 -C. Ten samples in minor fault bounded chert sequence distributed by within faults, 3.6 meters in thickness, on the first bench (middle part of the columnar section in Fig. 31 -B) contains the following radiolarian fossils: *Pseudoalbaillella* sp. cf. *P. fusiformis*, *P.* sp. aff. *P. longicornis*, *Albaillella asymmetrica*, etc. (Fig. 31 -B and Plate 6). They are considered to belong only one assemblage, and probably corresponds to the assemblages of *P. longtanensis* and *P. globosa* Zone. Thus, the 3.6 meters thick chert sequence includes there two zones. The chert sequence of the third bench of the outcrop yields conodont fossils, but they can not be determined even in genus level. No well-preserved radiolarian fossils occur with conodonts.

The exact horizons of the Carboniferous conodonts bearing samples, Y82050 and Y82051 (Oho *et al.*, 1985), are unknown because of the great size of the outcrop. Therefore, the exact Carboniferous and Permian boundary have not been placed yet. Many faults parallel on subparallel to beddings can be observed in this outcrop, thus the Permian - Late Carboniferous boundary in the chert may be a fault.

4. Radiolarian assemblage of the Maizuru and Ultra-Tamba Terranes in south of Oga region

The Maizuru Terrane and Ultra-Tamba Terrane rocks are widely distributed in the southeastern Hiroshima and

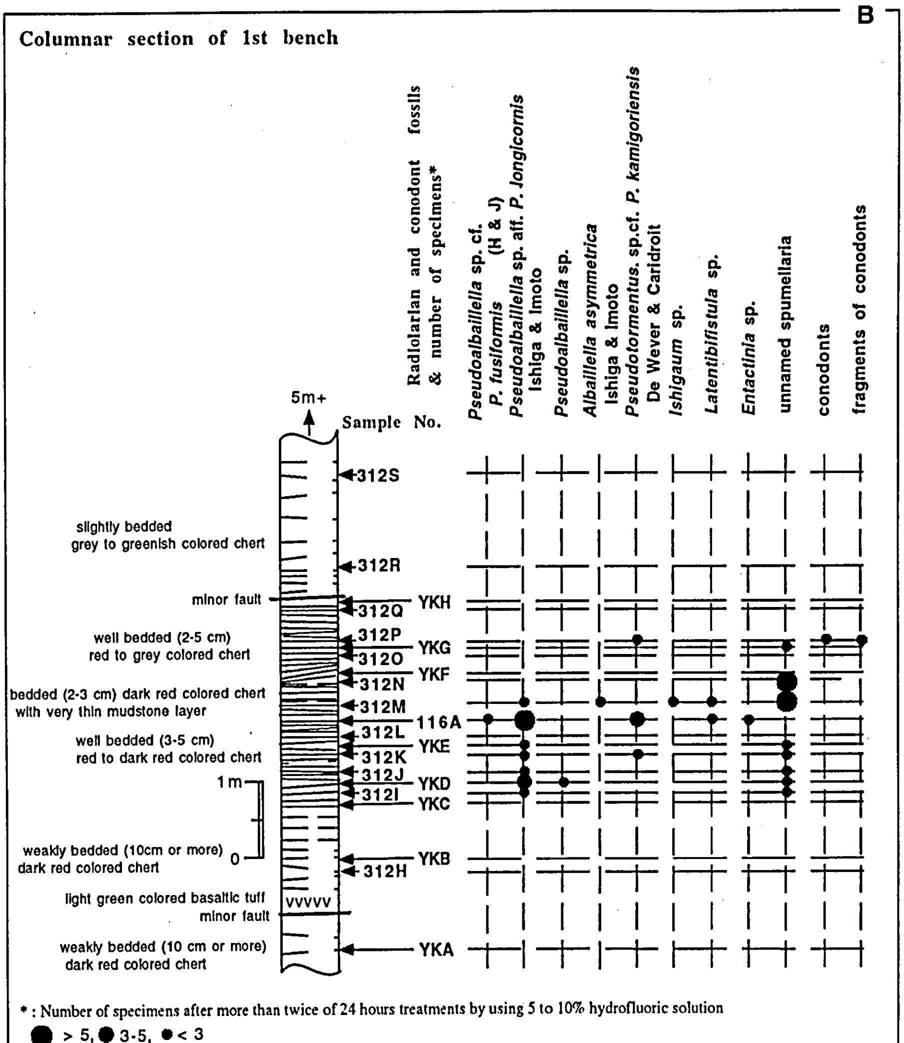
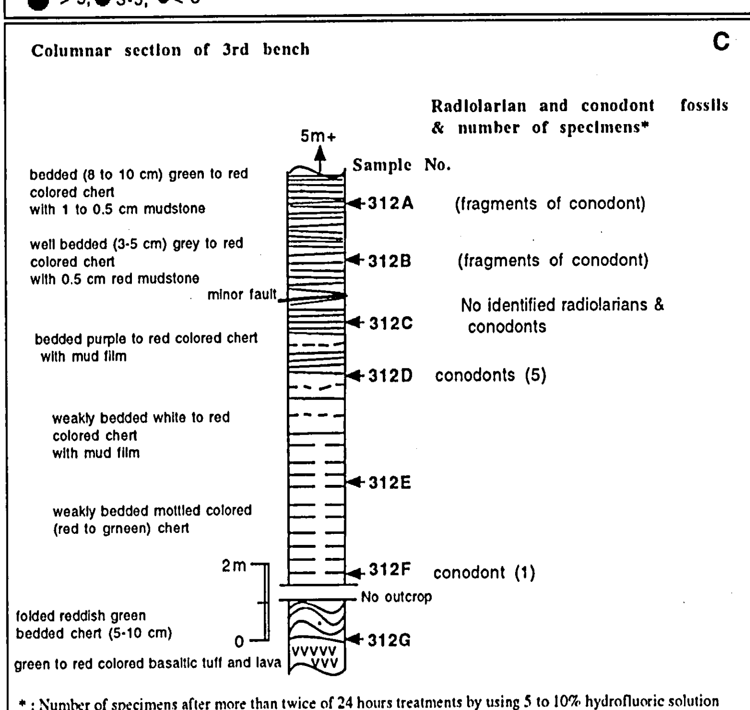
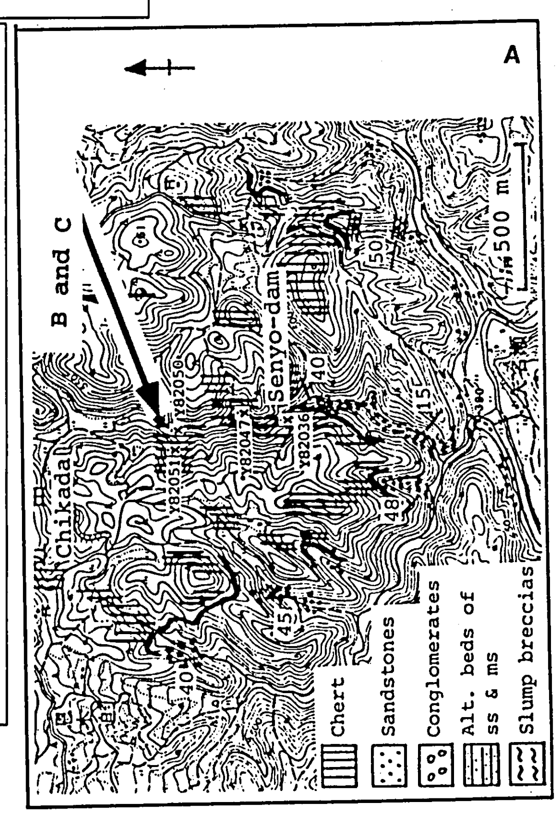


Fig. 31 : A ; A simplified geologic map after Oho *et al.* (1985) showing localities of the examined outcrops in this paper. The localities of conodonts by Oho *et al.* (1985) are also shown. The topographic map is a part of "Kobatake" on 1/25,000 scale by Geographical Survey Institute of Japan. B ; A columnar section of the first bench of a huge chert outcrop. Vertical distribution of radiolarian fossils are also shown. C ; A columnar section of the third bench of a huge chert outcrop. Horizons of conodont fossils are also shown.





southwestern Okayama Prefectural region, from Fukuyama City (West) to Takahashi City (East). The Permian radiolarian fossils from the two terranes have been reported in several areas (Suzuki *et al.*, 1987; Ishiga *et al.*, 1988, 1989; Tsutsumi, 1991; Sugata *et al.*, 1992).

Radiolarian fossils in this region found by the author are shown in Fig. 32. All sample localities are shown in Fig. 2.

Mudstone of Loc. 112B is included the Yamano Unit of Sugata *et al.* (1992), yield *Follicucullus* sp. which indicates Middle to Late Permian. Three radiolarian zones, *Pseudoalbaillella longtanensis*, *F. monacanthus*, and *F. scholastics* Zones have been already recognized in the Yamano Unit (Ishiga *et al.*, 1988).

Alternating beds of mudstone and silicic tuff of Loc. 303A contain radiolarian fossils as follows: *P.* sp. cf. *P. fusiformis*, *P.* sp. aff. *P. longtanensis*, *P.* sp. aff. *P. longicornis*, etc. The locality is out of the mapped area of Sugata *et al.* (1992), but it probably corresponds to the western extension of the Himetani Unit. If it is the case, these radiolarian fossils provide the first index of age determination of the unit. The assemblage probably corresponds to that of the *P. longtanensis* Zone. Thus, the Himetani Unit includes the early to middle Middle Permian strata. Additionally, the Himetani Unit is correlated to the UT-3 unit of the Ultra-Tamba Terrane by Sugata *et al.* (1992). The UT-3 in Kouzuki area includes the *F. bipartitus*- *F. japonicus* assemblage which is a characteristic radiolarian fauna recovered only from the Ultra-Tamba and Kurosegawa Terranes (Ishiga, 1990b). The radiolarian assemblages from the Himetani Unit clearly differ from those of the UT-3, therefore, detailed investigations of the Himetani Unit are required.

Mudstone of the Kurohagi Unit yields *F.* sp. cf. *F. japonicus* ?. *F. monacanthus*, *F. scholasticus*, etc. are already reported from the unit (Ishiga *et al.*, 1988) . The Kurohagi Unit is correlated to the Uji Formation by its age and lithology (Sugata *et al.*, 1992).

Unit and Terrane (after Sugata *et al.*, 1992)	Yamano (Ma)			Hm. (UT)	Miyama (UT)		Ku. (Ak)
Localities	112B	301	290	303A	90	93	243B
Radiolarians \ Lithologies	ms	ms	ms	ms/tf	ms/ss	ms/tf	ms
Follicucullus sp. cf. *F. japonicus* Ishiga							•
F. sp.	•						
Pseudoalbaillella sp. cf. *P. fusiformis* (H & J)				⬤			
P. sp. aff. *P. longtanensis* Sheng & Wang				●			
P. sp. aff. *P. longicornis* Ishiga & Imoto				●			
P. sp.				●			
Nazarovella sp. ?							
Unnamed spumellaria		●	●		•	•	

Number of specimens after more than twice of 24 hours treatments by using 5 to 10 % hydrofluoric solution : ⬤ > 5, ● 3 - 5, • < 3

Fig. 32 : Occurrences of the radiolarians of the southeastern Hiroshima and southwestern Okayama Prefectural region. All localities are shown in Fig. 2.

VI. Geologic structure

The regional geologic strictures, such as ones within a single formation and complex in the different areas were already mentioned in Chapter III. In this chapter, the geological structures are examined in a larger geographic scope. The recognized geologic structures are classified into four types of faults and three types of folds. A diagram showing classification of the geologic structure is given in Fig. 33.

A. Classification of macroscopic structure

The Carboniferous to Permian rocks in the Atetsu region are repeatedly deformed by many faults and folds. However, by a detailed mapping, these structural elements can be classified as below. The four types of faults are high angle fault, Terrane boundary (Tb), Nappe boundary (Nb), Intra-nappe fault, and the three types of folds are Terrane boundary bending fold (TbF), Nappe boundary bending fold (NbF) and Intra-nappe fold. Some important faults and folds are named in this paper, showing in Figs. 34 and 35.

1. fault

a. high-angle fault

The high-angle faults developed all over the region are easily recognized in the Atetsu region. Most of the fault planes of these faults are at vertical or acute angles, and horizontal displacements are remarkable. From the displacement direction, both of the left-lateral and right-lateral faults can be distinguished. For example, the Futatsugi Fault is a right-lateral fault, while the Dobashi Fault is a left-lateral one (Fig. 34). Fig. 34 shows the horizontal movement direction of these faults, and Fig. 35 shows the vertical displacements of it.

Most of the major left-lateral high-angle faults are NE-SW trend, whereas the right-lateral ones trend N-S or NW-SE. In the most cases, the left-lateral faults are cut by right-lateral ones, but a left-lateral fault called as the Sakamoto Fault, which extends to the Oga region (MITI, 1967), cuts the right-lateral ones (Fig. 34).

The high-angle faults clearly cut the Cretaceous silicic volcanic rocks (see Fig. 18). Some quartz porphyry dikes intrude along with the direction of this faults. These type faults, especially the left-lateral and NE-SW trending high-angle faults, are common in the Inner Zone of Southwest Japan.

b. Terrane boundary (Tb)

The faults bounded between the Akiyoshi and Suo Terranes, and the Akiyoshi and Sangun-Renge Belt are called as the Terrane boundary (Tb) in this paper. The Tb between the Akiyoshi and Suo is detailed analyzed in the Mio and Azae areas (Fig. 16 and 18), and is named the Mio Fault. The outcrop of the Mio Fault is seen in Loc. 1149, Matamaru (Fig. 18). A Fault breccia, 10 to 20 centimeters in thickness, occurs along the boundary surface. The strike and dip of the Mio Fault is parallel or sub-parallel to that of schistocity of the Suo Terrane, while they mostly forms at gentle angles with those of the bedding planes of the Fuyori Formation, Akiyoshi Terrane.

The Tb between the Akiyoshi Terrane and the Sangun-Renge Belt or Suo Terrane is recognized as a thrust in Mt. Oonoro and west of Niimi by Sugimoto *et al.* (1990; Fig.

Faults

Terms	Legend on Figs.	Definition & characteristics	Representatives	Age & phase
High angle fault		Common in central-western Chugoku district, generally trending NE-SW, high angle (90-70 degrees), including considerable lateral displacement, truncating or truncated by NW-SE or N-S high angle faults, displacing pre-Cretaceous strata, occasionally accompanied with intrusive rocks.	Nakatui Fault SaKamoto Fault	During or after Cretaceous, cuts axes of the TbF
Terrane boundary	or	Moderate to gentle dipping, separating terrane boundaries (Sangun-Renge/Akiyoshi Terrane, Akiyoshi/Metamorphics, Akiyoshi/Maizuru), bent by TbF, concordant with beddings of the bound strata.	Mio Fault	Afer the Suo Metamorphism (after Triassic), cut by the high angle faults
Nappe boundary		Separating nappes within the Akiyoshi Terrane, moderate to gentle dipping thrusts, commonly concordant but less frequently in an angle to beddings of the bound strata, rare in fault breccias.	Nitta Fault Morikuni Thrust	During or later than formation of the Akiyoshi accretionary complex
Intra-nappe fault		Occuring with in the Fuyori Nappe, moderate to low angle thrust, mostly concordant to bedding planes, truncated by Nb.		Earlier than Nb faults

Folds

Terms	Legend on Figs.	Definition & characteristics	Representatives	Age & phase
Terrane boundary bending fold (TbF)		Open, with a half wavelength of 1-3 km, axial planes trending E-W or NW-SE, planging W or NW, bending Tb faults, truncated by the high angle faults.	Azae Synform	Later than Tb faults, earlier than the high angle faults
Nappe boundary bending fold (NbF)		With a half wavelength of tens-handreds meters, axial planes trending N or SW, bending the Nb faults, bent by the TbF.	Tarumi Antiform Yokouchi Synform	Contemporary with or later than TbF
Intra-nappe fold		Restricted in the Fuyori and Atetsu Nappes, with a half wavelength of tens to 100 m, truncated by Nb faults, but unknown about the relationship to NbF.		Earlier than Nb faults

Fig. 33 : Classification of the faults and folds in the Atetsu region.

34). According to them and the author's investigation, The Tb moderately dips to the north, thus, the Sangun-Renge Belt tectonically overlies the Akiyoshi Terrane.

The Tbs are cut by the high-angle fault in several areas (e.g. Kawamoto Dam area in Fig. 3, Kusama area in Fig. 19, etc.).

c. Nappe boundary (Nb)

The Nappe boundary (Nb) is defined as the fault separating the nappes. The several faults have been regarded as the Nb in the Atetsu region based on distributions of the fusulinid zones of the Atetsu Limestone and repetition of the lithological sequence including basic volcanics and clastic rocks (Okimura *et al.*, 1981; Takeda and Nishimura, 1989).

The Nb between the Northern and Southern Facies of the Atetsu Limestone, called the Morikuni Thrust, can be distinctly traced through the whole of the Atetsu region (Fig. 34). The strike and dip of the Morikuni Thrust is generally coincide with those of the both bounded facies of the Atetsu Limestone, but in several areas thrusts and beddings obviously form an angle of less than 30° (see geologic maps; Figs. 16, 18 and 19). It is not accompanied with fault breccia and its surface is irregularly undulating as observed in the road cutting from Terauchi to Hanagi.

The Nb between the Southern Facies of the Atetsu Limestone and the Fuyori Formation, named the Nitta Fault, is also obvious. The strike and dip of the Nitta Fault is mostly concordant with those of the Southern Facies of the Atetsu Limestone which occupies the hanging wall side. While the structure of the Fuyori Formation (foot wall side) is cut by the Nitta Fault.

The Nbs are obviously cut by the high-angle faults. The Nb is presumably cut by the Tb in Mio area. In north of Mio area, the limestone body, 500 meters long (NW-SE) and 300 meters width (NE-SW), with basic volcanic rocks occurs in a separated area from the main part of the Atetsu Limestone (refer to Fig. 16). The northern end of the body is in a fault (Tb, Mio Fault) contact with the Suo Terrane, while the southern end is probably bounded by a "fault" with the Fuyori Formation. The "fault" can be probably correlated to the Nb for the following reasons. The limestone body yields the Late Carboniferous smaller foraminifera, such as *Eostaffella* sp., etc. (MITI, 1980). MITI (1980) considered that the limestone body is a member of the metamorphic rocks group (Suo Terrane in this thesis), but this idea is hardly acceptable, because the limestones was not suffered in a strong metamorphism. Therefore, the limestone and basic volcanic rocks can be correspond to the Southern Facies of the Atetsu Limestone, that is supported by the similar limestone lithology (mainly peloidal intramicrite by MITI, 1980). In the south of this limestone body, the Southern Facies of the Atetsu Limestone is separated by the Nb from the Fuyori Formation. Therefore, the "fault" is probably regarded as the Nb. The distribution of the limestone body in the north of Mio, thus indicates that the Nb is cut by the Tb.

d. Intra-nappe fault

In the area of the Fuyori Formation, some faults are inferred from the repetition of the same lithology and from

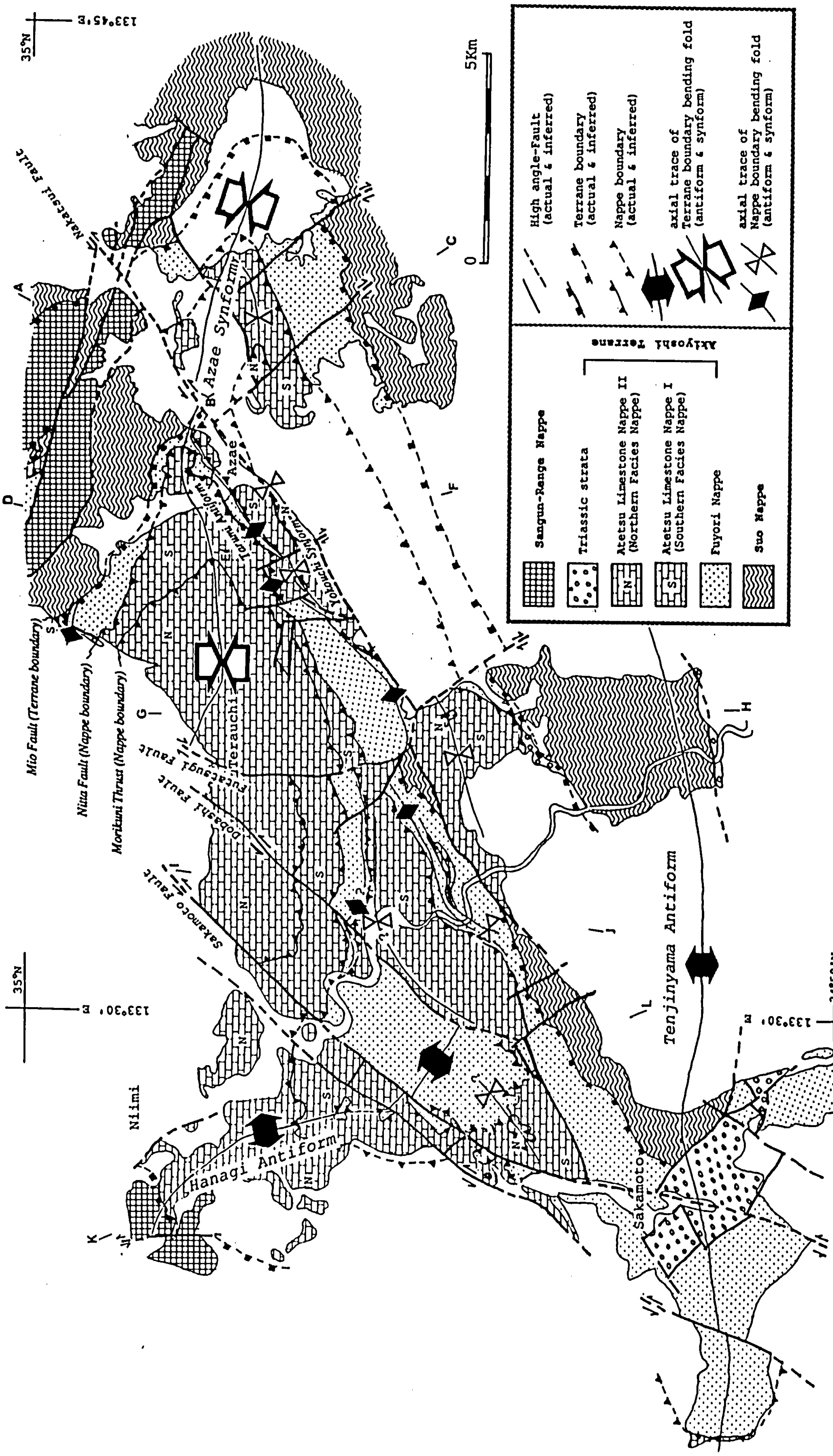


Fig. 34 : A simplified structural map of the Atetsu region. Name of some important faults and folds are shown.

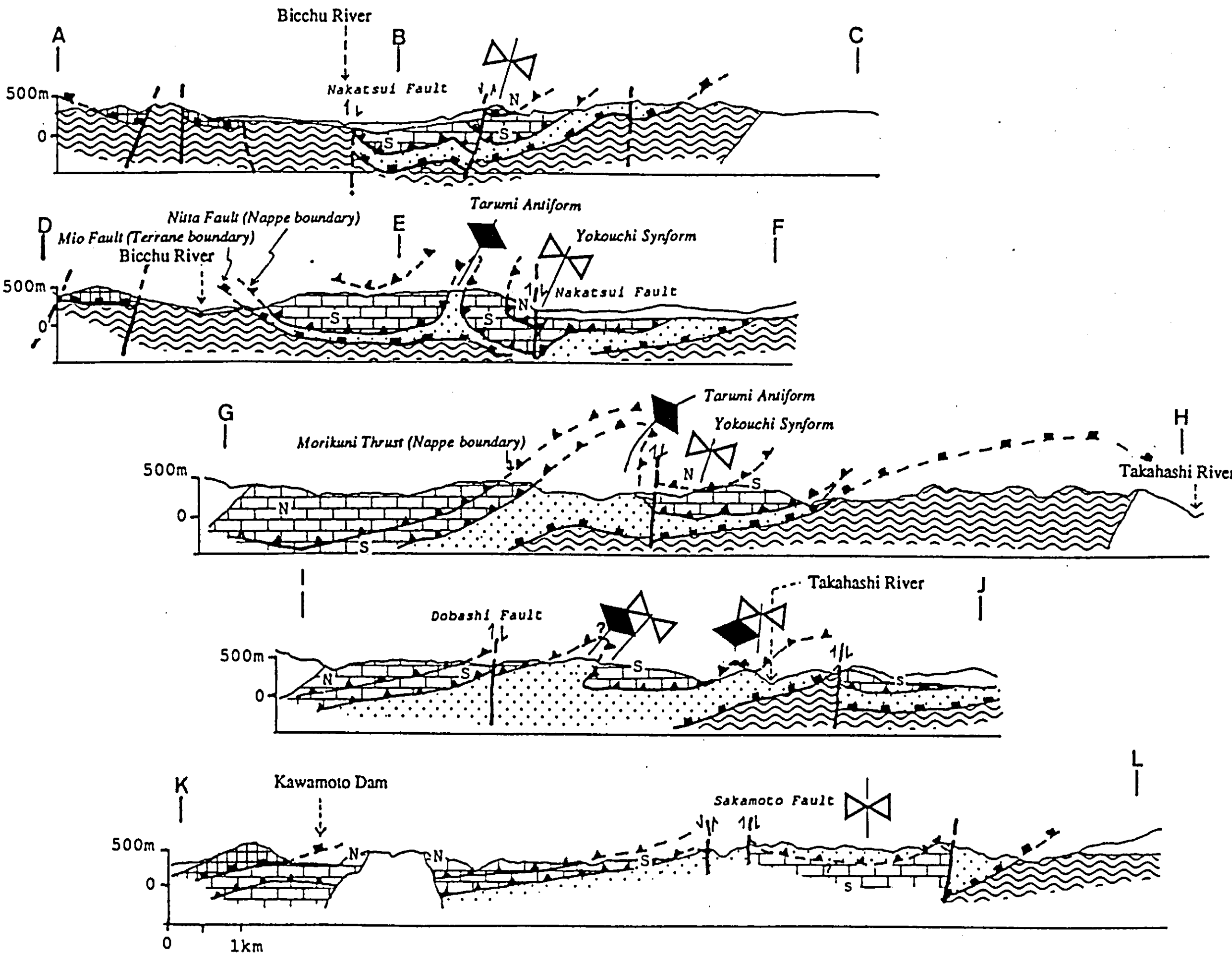


Fig. 35 : A simplified cross sections of the Atetsu region. Axial plane of the some Nappe boundary bending folds are shown. Note that the scale differs from that of in Fig. 34.

the inconsistency between the apparent successions (see Figs. 16 and 18). These faults are cut by the Nb, Tb and high-angle faults. Thus, these faults are here called as the Intra-nappe faults. The Intra-nappe fault is the earliest phase of the faults in the Atetsu region.

2. fold

a. Terrane boundary bending fold (TbF)

The folds, which obviously bent the Terrane boundary, are defined here as the Terrane boundary bending fold (TbF). They are already recognized in the stratigraphic studies of the Atetsu Limestone (Okimura *et al.*, 1981; Otoh, 1987).

The TbF are symmetrical, open, characterized by general plunging of westward, and exhibit broad synforms and antiforms. Its wavelength is 5 to 10 kilometers order.

For example, one of the TbF is traceable in Azae to Terauchi area (Fig. 34, also refer to the detailed geologic maps of Figs. 11 and 18), which is named here as the Azae Synform. It is recognized from tracing the boundary between the Akiyoshi and Suo Terranes. The Azae Synform bent not only Tb but also Nappe boundaries and the strikes and dips of the Atetsu Limestone and "Northern" Terauchi Formation. In Azae to Terauchi area, the Atetsu Limestone and "Northern" Terauchi Formation trend WNW and dip northward in southern part of the area, while they trend NW and dip southwestward in northern part of the area. The Azae Synform has the half wavelength of approximately 5 kilometers and the axes plunging westward, thus, rocks and faults are distributed in a horseshoe shape convex eastward (Fig. 34). The axis of the Azae Synform is displaced by the NE-SW trending left-lateral high angle fault, Nakatsui Fault, along the Nakatsui River, but it can be followed to the east.

The other TbF can be observed in south of Niimi (Fig. 34), where the Tb between the Akiyoshi Terrane and the Sangun-Renge belt is bent. The TbF of this area, called the Hanagi Antiform, also bends the Nb between the Northern and Southern Facies of the Atetsu Limestone. According to Okimura *et al.* (1981), the Ishiga Formation cropped out as a tectonic window surrounded by the Southern Facies of the Atetsu Limestone near Takaino (Fig. 34). While in the bounded area by two left-lateral high angle, Sakamoto and Dobashi Faults, around Ogyou (Fig. 34), Okimura *et al.* (1981) illustrated that the Ishiga Formation unconformably overlies the Atetsu Limestone and forms a syncline. However, distributing pattern and structural position of the Ishiga Formation seem to indicate that the axis of the Hanagi Antiform is extended to this area although the extension of the axis to SE direction should be proven by further detailed investigation. The

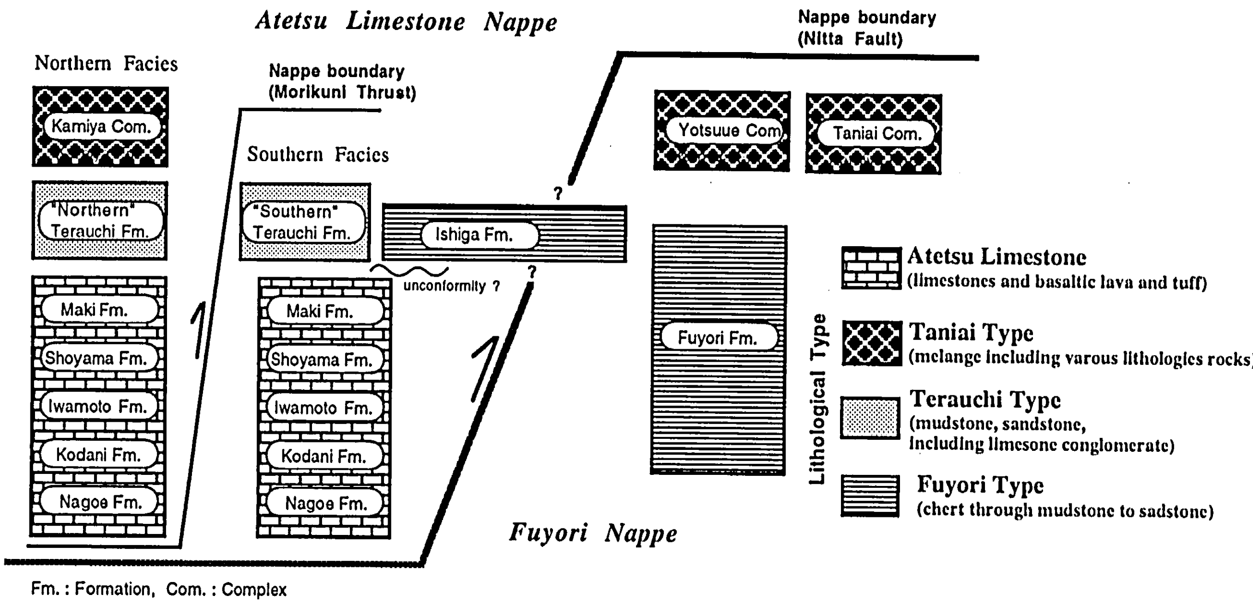


Fig. 36 : A schematic diagram of the nappe structures in the Atetsu region. The formations and complexes, which are component of the nappes, are shown.

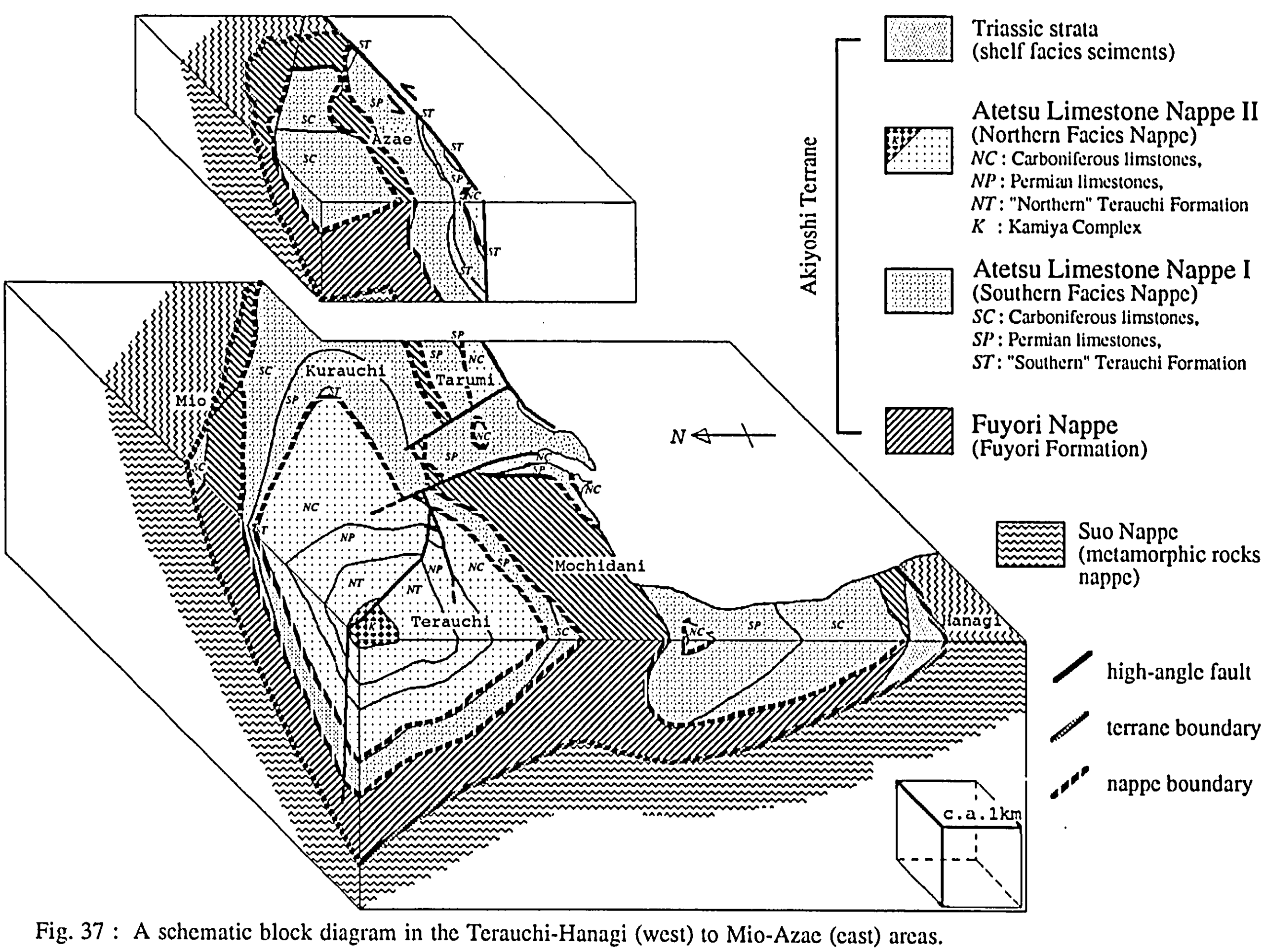


Fig. 37 : A schematic block diagram in the Terauchi-Hanagi (west) to Mio-Azae (east) areas.

Hanagi Antiform trends NW-SE and moderately plunges northwestward in the area where the southern end is bounded by the Sakamoto Fault.

Another TbF, the Tenjinyama Antiform, is traceable from Mt. Tenjin (west) to Houkoku (east) areas (Fig. 33). This TbF is proven by the tracing of the Tb between the Akiyoshi and Suo Terranes and by the distributions of the

Suo Terrane rocks, Triassic strata, and the Fuyori Formation. The TbF trends E-W with a westward plunging.

These characteristic folds can be recognized in whole of the Inner Zone of Southwest Japan, especially Chugoku district and it has been considered that they were formed after the sedimentation of the Lower Cretaceous formations.

b. Nappe boundary bending fold (NbF)

The folds, which bent the Nappe boundary between the Fuyori Formation and the Atetsu Limestone, are here defined as the Nappe boundary bending fold (NbF). This paper first recognized the NbF in the Atetsu region.

The synforms and antiforms of the NbF are asymmetrical, tight to gentle, and exhibit relatively short wavelength. However, the characteristics of some NbF developed in the Atetsu Limestone resemble to those of the TbF. Therefore, the discrimination of both folds, NbF and TbF, only depends on bending the Tb or Nb.

The NbF can be typically recognized from Azae to Yokouchi areas (Fig. 34, and refer to the detailed geologic map and cross sections of Fig. 18). In this area, the appearance of "two" northern and southern Nappe boundaries within the Fuyori Formation generally trend ENE-SWS and dip moderately northward. The Atetsu Limestone belonging to the Southern Facies distributed northern part of the areas trend nearly the same direction with that of "northern" Nappe boundary. In contrast, the Atetsu Limestone distributed in the southern part of the areas, belonging to the Southern and Northern Facies, are completely overturned that is inferred by the distribution of the fusulinacean zones and presence of the "Southern" Terauchi Formation. Therefore, apparent two "Nappe boundaries", the northern and southern borders of the Fuyori Formation, can be assigned to the one Nappe boundary (Nitta Fault) which is the bottom of the Atetsu Limestone resting on the tectonically underlying Fuyori Formation. The NbF, called as the Tarumi Antiform, bents the Nappe boundary surface, and the axial plane of the antiform dips moderately northward. The antiform is asymmetric. The northern limb moderately dips to northward, while southern limb consists of reversed strata steeply dipping to northward (Figs. 18 and 35). The Fuyori Formation crops out along the axis of the Tarumi Antiform.

The western extension of the Tarumi Antiform can be intermittently traceable from Yokouchi through Mochidani to Ikura (Fig. 19), because the Atetsu Limestone in southern part bounded with the Fuyori Formation are overturned with a dip to north, or normal with a dip to south (Sada, 1965; Sakamoto, 1991MS). In these areas, the axial plane of the antiform dips steeply or gently northward (see the G-H cross section in Fig. 35).

The overturned Southern Facies of the Atetsu Limestone is also found in northern part of Mio area, and is tectonically located between the Fuyori and Suo Nappes (Figs. 16 and 17). Thus, the Tarumi Antiform is also extended northward, but the axis of the antiform was truncated by the Terrane boundary (Mio Fault) in northern Azae to southern Mio areas.

The paired synform, which called as the Yokouchi Synform, with the Tarumi Antiform can be recognized within the Atetsu Limestone in Yotsuune, Hanagi and Ikura areas (Figs. 18 and 19), where the axial planes dip steeply or gently northward (Fig. 34). A part of the southern wing of the antiform and the northern wing of the synform are mostly missed by high-angle faults.

The eastern extension of the Yokouchi Synform is probably traced in the Yotsuune area. The Southern Facies of the Atetsu Limestone and tectonically overlying the Northern facies here form the synform (Sakamoto, 1991MS, Fig. 34). The axial plane dips steeply northward and the plunging of axis dips moderately to the west.

c. Intra-nappe fold

In the area of the Fuyori Formation, some folds are recognized (Figs. 18 and 19). The axes of these folds are cut by the Nb, Tb and high-angle faults. Thus, these faults call here as the Intra-nappe folds. For example, the Fuyori Formation in Tarumi area exhibits NW-SE or N-S trending folds (Fig. 18). It is unclear whether these fold axes were bent or not, by the Tarumi Antiform. However, these folds were probably formed before developing of the Tarumi Antiform, because these folds axes were truncated by the Nappe boundary.

B. Nappe structure in the Atetsu region

By a detailed mapping and classification of macroscopic structure, many nappes were here recognized in the Atetsu region. They are grouped into major four nappes and are named as, the Sangun-Renge Nappe, Atetsu Limestone Nappe, Fuyori Nappe, and Suo Nappe, in tectonically descending order. Among these, the Akiyoshi Limestone and Fuyori Nappes occur within the Akiyoshi Terrane (Fig. 36). The Sangun-Renge Nappe and Suo Nappe represent by the rocks of the Sangun-Renge Belt and metamorphic rocks belonging the Suo Terrane, respectively. The Sangun-Renge Nappe tectonically overlies the Atetsu Limestone Nappe, while the Suo Nappe tectonically underlies the Fuyori Nappe.

It is noteworthy that the recognition of the Nappe boundary bending folds, especially the Tarumi Antiform and Yokouchi Synform, revealed presence of the two major nappes, Atetsu Limestone and Fuyori Nappes, developed in the Atetsu region (Figs. 36 and 37). Thus, the nappe structure of this paper differs from that of Otoh (1987), because of the added information by the recognition of the Nappe boundary bending folds.

The Atetsu Limestone Nappe is bounded by the Nitta Fault with the tectonically underlying Fuyori Nappe. It consists of the Atetsu Limestone, Terauchi Formation, and the Kamiya Complex. The Atetsu Limestone Nappe is subdivided into two nappes, the Southern and Northern, which are named the Atetsu Limestone Nappe I and Atetsu Limestone Nappe II, by the repetition of the fusulinid zones (Figs. 36 and 37). The Southern Facies of the Atetsu Limestone sub-Nappe (Nappe I) is tectonically overlaid by the Northern one (Nappe II).

The Fuyori Nappe is bounded by the Nitta Fault with the Atetsu Limestone Nappe, and by the Terrane boundary (Mio Fault) with the Suo Terrane. It is distributed in two or three narrow belts in the Atetsu region with a general ENE-WSW direction affected by Nappe boundary bending folds. Until the recognition of the NbFs in this paper, two or three belts of the nappe had been considered as different nappes by Otoh (1987). The nappe is composed of the Fuyori Formation, Taniai and Yotsuune Complexes. The

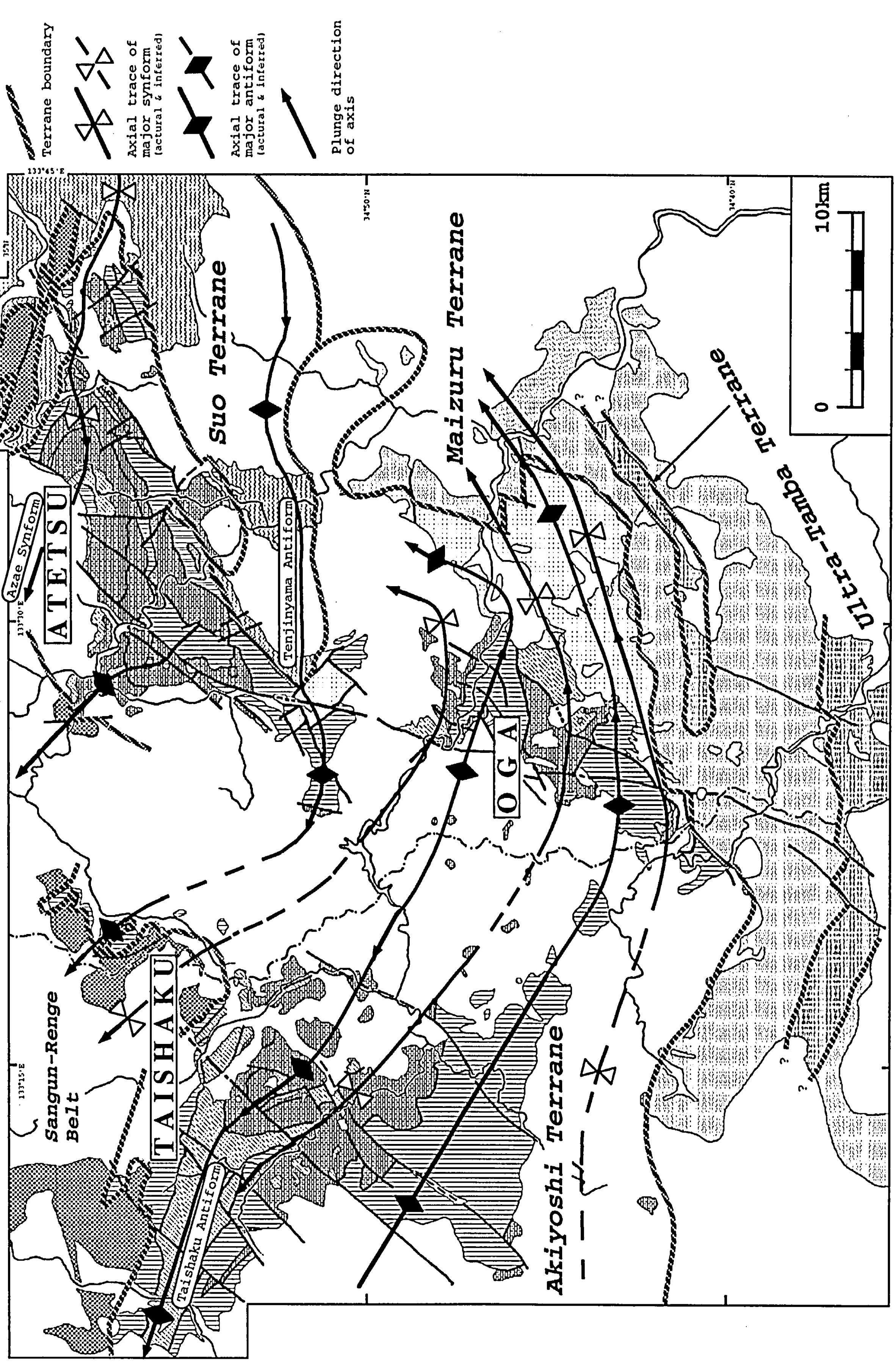


Fig. 38 : A simplified structural map in the Atetsu, Taishaku, and Oga regions. The axial trace of major folds and the Terrane boundary are shown. See legend of Fig. 2. See the text for discussion.

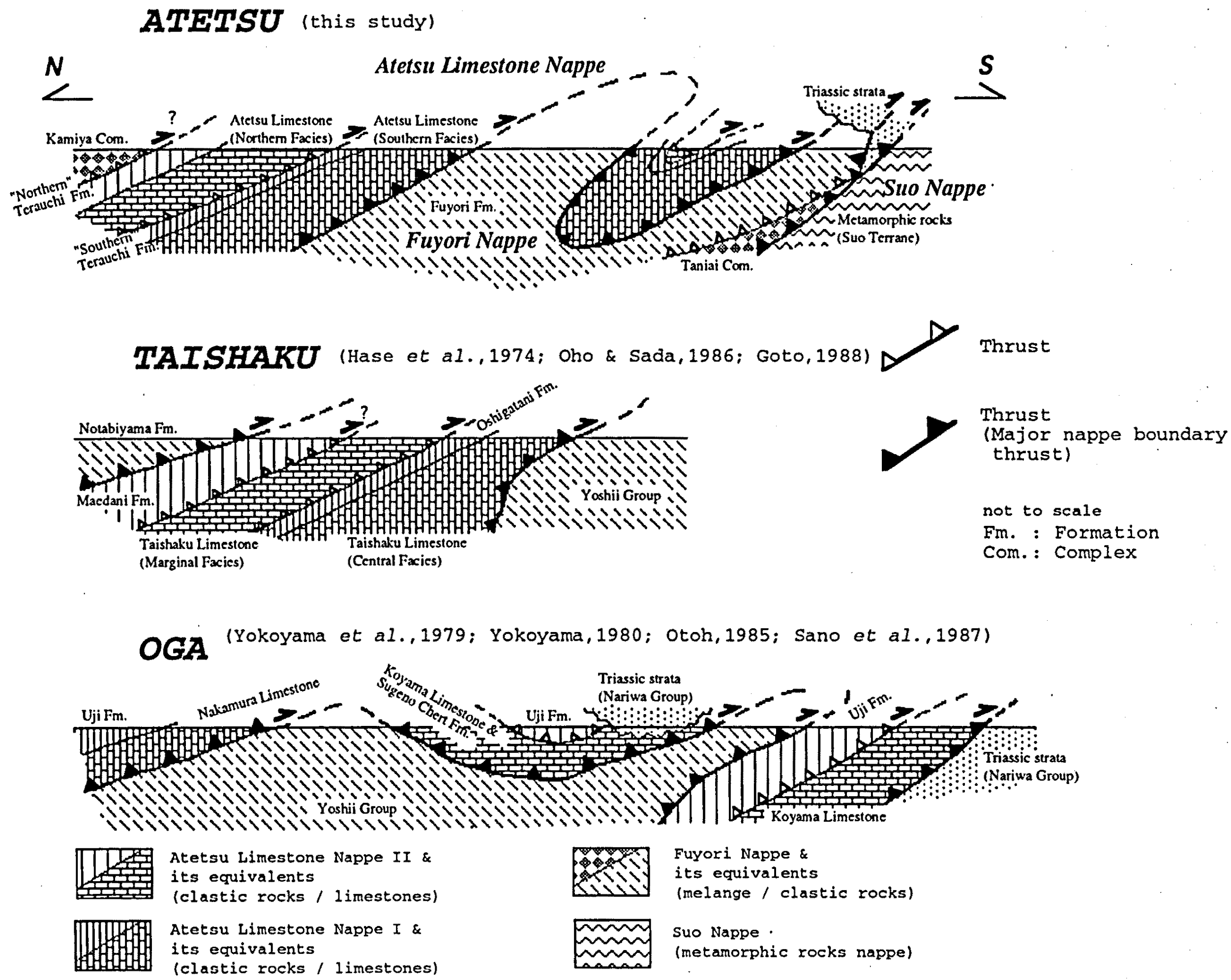


Fig. 39 : Idealized cross sections of the Atetsu, Taishaku, and Oga regions. See the text for discussion.

part of the Ishiga Formation is excluded from this nappe, because the southern part of the Ishiga Formation is unconformably overlies the underlying Atetsu Limestone (Okimura *et al.*, 1981). In Mio and Azae areas, several Intra-nappe faults were recognized within the Fuyori Formation, and thus the Fuyori Nappe probably consists of several sheets.

VII. Correlation of the stratigraphy and geologic structure

The correlation of the lithostratigraphy of the siliceous and terrigenous clastic rocks, and geologic structure between the Atetsu region and the Taishaku and Oga regions are described. The correlation is based on previous publications and the author's investigations.

A. Stratigraphic correlation

The Fuyori Formation in the Atetsu region is characterized by a succession from chert through mudstone to sandstone. The similar succession is reported in the Taishaku and Oga region as the Notabiyama Formation and the Yoshii Group, respectively (Goto, 1988; Sano *et al.*, 1987). The characteristics of component rocks are also similar among the formations and group (Figs. 6 and 42). Especially, radiolarian bedded chert is included in all of the three rock units. Noteworthy, silicic tuff layers of the late Middle Permian are frequently intercalated in the three units. Thus, these rock units are grouped into as the Fuyori Type (see Fig. 6).

The "Northern" and "Southern" Terauchi Formations are undoubtedly correlated to the Maedani and Oshigatani Formations in the Taishaku region from their lithology and stratigraphic position (Fig. 5). The lithology of the Uji Formation somewhat differs to the Terauchi Formation, because the Uji Formation is characterized by larger limestone bodies enclosed in mudstone matrix and lacks the thick sandstone unit. However, the mode of occurrences of the limestone bodies (Sano *et al.*, 1987) is closely similar to the limestone conglomerate of the Terauchi Formation. The differences in size of limestone blocks and the sandstone unit are probably due to the difference in the depositional environments of these formations.

The melange suites of the Kamiya, Yotsuune and Taniai Complexes in the Atetsu region are not recognized in the Taishaku and Oga regions. However, the lithology of the some parts of the Uji Formation seem to resemble that of the Yotsuune Complex although the stratigraphic and structural positions of both rock units are quite different. The Taniai Type in the Atetsu region may correspond to the Olistostrome in the Katsuyama region reported by Miyake (1985).

The Southern Facies of the Atetsu Limestone can be correlated to the Central Facies of the Taishaku Limestone Group (Hase *et al.*, 1974) which indicates the center of a reef complex. While the sediments of Northern Facies of the Atetsu Limestone resemble the Marginal Facies of the Taishaku Limestone, which represents the depositional setting of a fore reef flank (see Fig. 5).

B. Structural correlation

The geologic structure of the Akiyoshi Terrane in the Atetsu region is characterized by the nappe structure, especially two major nappes; the Atetsu Limestone Nappe and Fuyori Nappe. The most important feature of the nappes is bending by the Terrane boundary bending folds and Nappe boundary bending folds. The simplified structural map of the Atetsu, Taishaku, and Oga regions, and idealized cross sections of the three regions are given in Figs. 38 and 39, respectively.

In northern Taishaku region, the structural contact among formations has been discussed. Goto (1988) reported that the whole of Notabiyama Formation thrusts over the Maedani Formation. This is contrary to the Oho's (1985) conclusion that only chert of the Notabiyama Formation thrusts over the Maedani Formation. In the geologic map by Goto (1988), the relationship between the Maedani Formation and the underlying Taishaku Limestone was drawn as a fault, although conformable contacts between the two had been observed in several areas (Hase *et al.*, 1974; this study, Fig. 29). The Taishaku Limestone is divided into two facies, Central and Marginal Facies, bounded by a thrust (Hase *et al.*, 1974). In the southern Taishaku region, the Taishaku Limestone tectonically rests on the Yoshii Group (Oho and Sada, 1986).

Thus, in the Taishaku region, the four nappes of the Akiyoshi Terrane can be recognized. In the tectonically descending order, they are the Notabiyama Formation, the Marginal Facies of the Taishaku Limestone, the Central Facies of the Taishaku Limestone, and the Yoshii Group. Moreover, metagabbro and serpentinite which may correlated to the Sangun-Renge Belt probably tectonically overlie on the Notabiyama Formation. The ordering of the nappes in the Taishaku region is quite similar to that of the Atetsu region (Fig. 39), except for the position of the Notabiyama Formation. The two Taishaku Limestone nappes and the Yoshii Group nappe can be safely corresponds to the Atetsu Limestone and the Fuyori Nappes, respectively. The nappe of the Notabiyama Formation, which occupies the position between the Marginal Facies of the Taishaku Limestone and the overlying Sangun-Renge Belt, was not recognized in the Atetsu region. Its tectonic position seems to be the same to that of the Kamiya Complex in the Atetsu region. However, the Kamiya Complex is presumed to conformably rest on the "Northern Terauchi Formation.

In Oga region, the geological structure is very complicated. In the northern Oga region, the Nakamura Limestone and the Koyama Limestone probably thrust over the Yoshii Group (Yokoyama *et al.*, 1979). Their relationship is correlated to that of the Atetsu Limestone Nappe and Fuyori Nappe. In southern Oga region, however, the Triassic strata, Koyama Limestone, Uji Formation, and the Yoshii Group form a pile nappe structure (Sano *et al.*, 1987). Basically, the nappe structure in northern Oga region is similar to that of the Atetsu region, but the southern region is quite different from the Atetsu region (Fig. 39). The reason of the difference is unclear.

The major open folds are found in the Taishaku and Oga regions. The axial trace of major folds trends NW-SE and plunges northward in the Taishaku region (Fig. 38). While the folds in the Oga region are traced along E-W or NE-SW direction and plunge to E or NE (Fig. 38). Besides the slight difference in direction, the open folds in the two regions exhibit similar wavelength of 5 to 10 kilometers. The connection of the axial trace of these folds between the Taishaku and Oga regions is estimated as shown in Fig. 38. Some of the major folds obviously bent the Terrane boundaries, and characteristic of these folds resembles to that of the Terrane boundary bending fold in the Atetsu region. The Nappe boundary bending folds which are recognized in the Atetsu region are not clear in the Taishaku and Oga regions.

VIII. Discussion

A. Correlation between the radiolarian and fusulinacean biostratigraphics

Radiolarian fossils commonly occur in fine-grained siliceous rocks and terrigenous clastic rocks including bedded chert, siliceous mudstone, silicic tuff, mudstone, and mudstone part of alternating beds of sandstone and mudstone, and their age determination by the co-occurrence with conodont fossils (e.g. Ishiga, 1986b, 1990b). While, fusulinid fossils are mostly found from limestones. The co-occurrence of them in a single sample has not been reported yet.

Correlation between radiolarian zones with fusulinacean zone is important especially in the Akiyoshi Terrane, because it can determine the exact age of collision and accretion events of a sea mount capped by limestone and surrounding terrigenous clastic rocks. It also supports the discussion the accretion history of the Akiyoshi Terrane.

An attempt of the correlation between the radiolarian and fusulinacean zones based on conodont biostratigraphy has been done from Late Carboniferous to Permian time by Ishiga (1990b), because conodont fossils occur from both limestone and chert facies. In the Middle to Upper Permian clastic strata including clastic limestone lenses and limestone conglomerates, the comparison of the two zones (radiolarian and fusulinacean zones) has been attempted in the following procedure. The radiolarian zone, *Follicucullus bipartitus -F. charveti* Assemblage Zone (recently redefined as *F. charveti* Zone by Ishiga, 1991) occurs in mudstone of the Kuma Formation, Kyushu region (Miyamoto *et al.*, 1985). The Kuma Formation includes the fusulinid zones, *Lepidolina multiseptata shiraiwensis* Zone, *Lepidolina kumaensis* Zone, and *Codonofusiella kwangsiana* Zone (Kanmera and Nakazawa, 1973; Ishii *et al.*, 1975; Sugiyama and Ozawa, 1989). The *F. charveti* zone is found in the *L. kumaensis* Zone. Furthermore, Sugiyama and Ozawa (1989) reported "*F. scholasticus*" from the *L. multiseptata shiraiwensis* Zone,

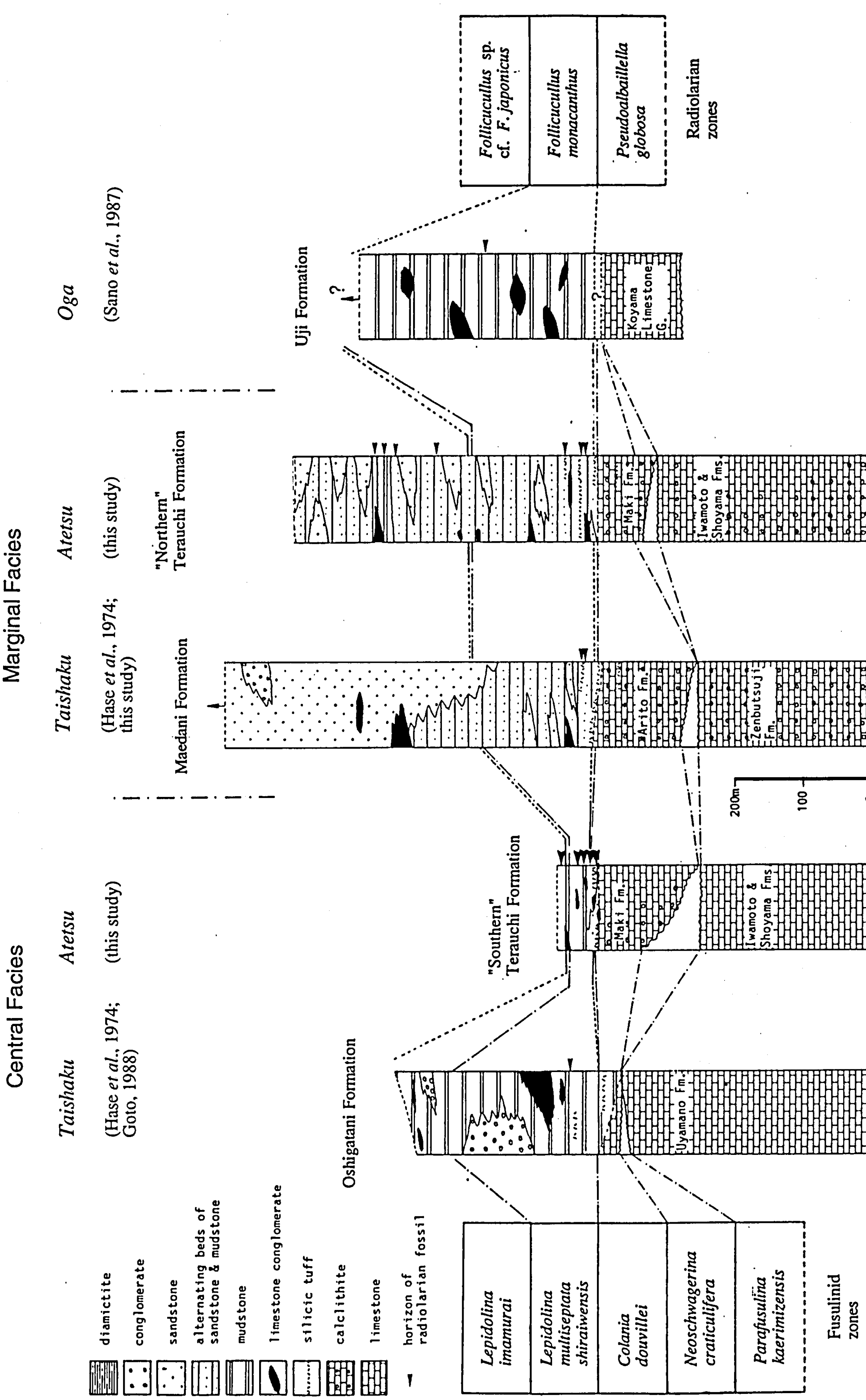


Fig. 40 : A diagram showing the correlation between the radiolarian and fusulinacean biostratigraphies on the general columnar sections in the Atetsu, Taishaku and Oga regions.

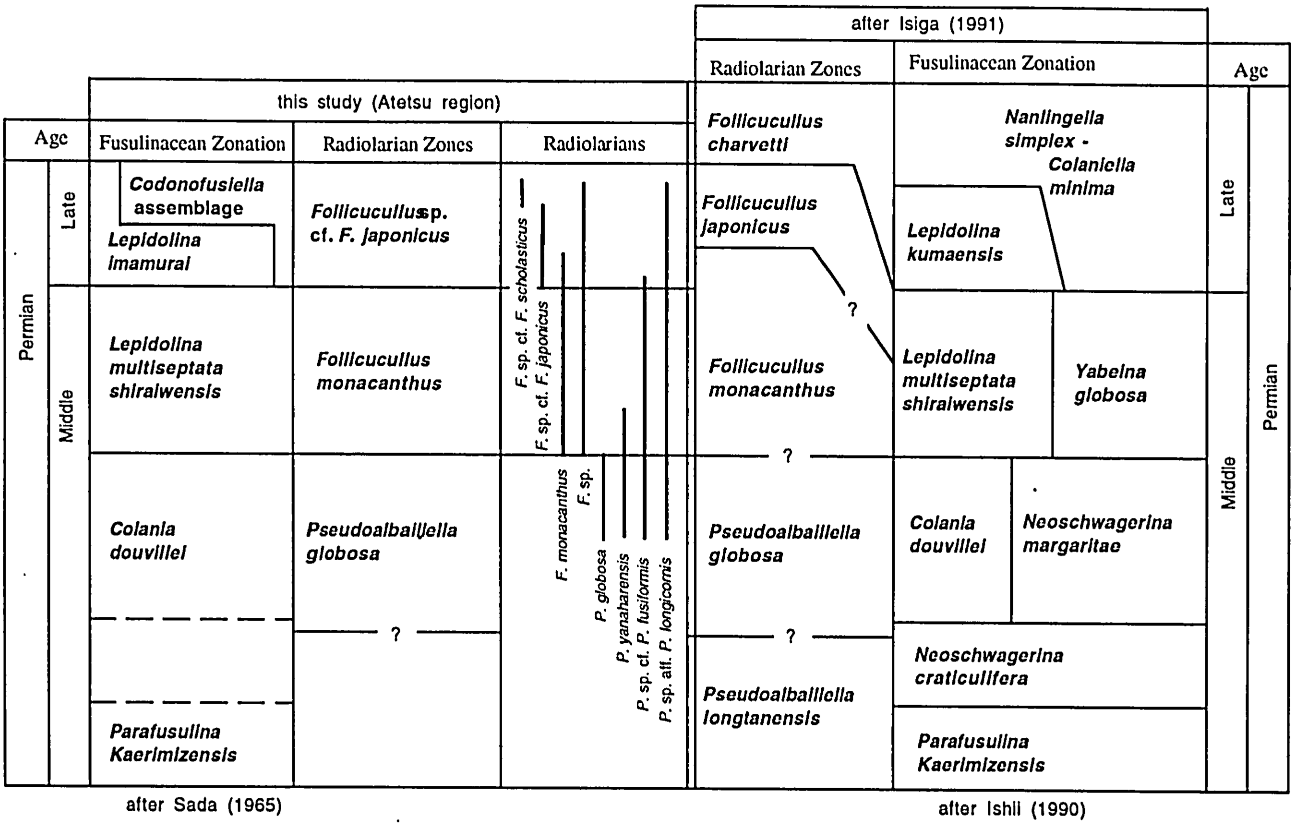


Fig. 41 : A diagram showing he correlation between the radiolarian and fusulinacean biostratigraphies in the Atetsu region (left part). The comparison of the results of the correlation by the author and Ishiga's (1991) compiling data of the Southwest Japan is also presented. See the text for discussion.

although the definition of "*F. scholasticus*" has been confused until the redefinition of *F. japonicus* by Ishiga (1991; see Chapter V). *F. japonicus* and *F. monacanthus* which correspond to *F. japonicus* Zone have been reported from mudstone of the Maizuru Group, Maizuru Terrane, where the radiolarian-bearing strata are correlative with the *L. kumaensis* Zone (Ishiga, 1984). Yamashita and Ishiga (1990) reported *F. monacanthus* and other radiolarian fossils representing the *F. monacanthus* Zone from the silicic tuff in the lowermost "Northern" Terauchi Formation which includes *L. multiseptata shiraiwensis* Zone, and they presumed to correlate the two zones.

The author attempts the correlation between the radiolarian and fusulinacean zones of the late Middle to early Late Permian based on data from the "Northern" and "Southern" Terauchi Formation in the Atetsu region and the Maedani Formation in the Taishaku region. The attempt is done in considering the following two conditions.

(1) The fusulinacean zone of limestone conglomerates is defined by the occurrence of the youngest fusulinid fossil, because the limestone conglomerates usually include various-aged fusulinid fossils. Thus, the age of mudstone which include the limestone conglomerate can be same or younger than the fusulinacean zone of the youngest species.

(2) The radiolarian zone and fusulinacean zone defined from the intercalating beds of spicular chert (or silicic tuff) and calclithite are same.

On the basis of these two conditions, the correlation between the radiolarian (R) and fusulinacean (F) zones is discussed as follows. The fusulinacean zones in the Atetsu and Taishaku regions are after Sada (1965) and Hase *et al.*, (1974).

The spicular chert of the *Pseudoalbaillella globosa* Zone (R) is intercalated with the calclithite and limestone conglomerate of *Colania douvillei* Zone in the Arasako section of the "Southern" Terauchi Formation (Fig. 15). From the condition (2), both zones can be safely correlated.

The boundary between the *P. globosa* (R) and *Follicucullus monacanthus* Zones (R) are settled in siliceous mudstone in this section (Fig. 15), but here the upper limit of the *C. douvillei* Zone (F) is not clear.

The lower part of the Lower Member of "Northern" Terauchi Formation includes the *F. monacanthus* Zone (R). The limestone conglomerate, included in the same horizon, yields fusulinid fossils of the *Lepidolina multiseptata shiraiwensis* Zone (F). The lower limit of *F. monacanthus* Zone (R) is placed within the "Northern" Terauchi Formation, but the upper limit of the *C. douvillei* Zone (F) is placed at the boundary between the underlying Maki (Atetsu Limestone) and "Northern" Terauchi Formations. Thus, the *F. monacanthus* Zone (R) overlies the *C. douvillei* Zone (F). In the Taishaku region, the *F. monacanthus* Zone is also conformably covered by *C. douvillei* Zone. From the condition (1), the lower limit of the *F. monacanthus* Zone (R) probably correspond to the base of *L. m. shiraiwensis* Zone (F).

The *Lepidolina imamurai* Zone (F) defined by Sada (1960, 1965) overlies the *L. m. shiraiwensis* Zone (F). The boundary between the two is placed within the Lower Member of the "Northern" Terauchi Formation. The first occurrence of *F.* sp. cf. *F. japonicus* is recognized near the same horizon of the boundary between these two zones. Limestone conglomerate in the "Southern" Terauchi Formation yields *Codonofusiella* sp. assemblage which probably indicates the younger zone than *L. m. shiraiwensis* Zone (F). The horizon of *Codonofusiella* sp. assemblage covers *L. m. shiraiwensis* Zone and also overlies *F. monacanthus* Zone (R). Thus, from the condition (2), the upper limit of the *L. m. shiraiwensis* Zone (F) is probably correlated to the horizon of the first occurrence of *F.* sp. cf. *F. japonicus* (*F.* sp. cf. *F. japonicus* Zone, see Chapter V).

In summary, the correlation between the two biostratigraphies in the Atetsu region is as follows.

a). The base of the *F. monacanthus* Zone (R) is presumably correlated with the base of the *L. m. shiraiwensis* Zone (F).

b). The first occurrence of *F.* sp. cf. *F. japonicus* is placed at the same horizon of the base of the *L. imamurai* Zone (F) and at the horizon of *Codonofusiella* sp. assemblage.

The diagram showing the correlation between the two zones on general columnar sections in the Atetsu and Taishaku regions is given in Fig. 40.

Fig. 41 shows the comparison of the results of the correlation by the author in the Atetsu region and Ishiga's (1990b, 1991) compiling data of the Southwest Japan. Judgments from his description (Ishiga, 1991), the base of the each radiolarian zone; *P. globosa*, *F. monacanthus*, and *F. japonicus* Zones, are not directly correlated to the fusulinacean zone boundaries. It is noteworthy that the bases of *F. monacanthus* Zone and *F.* sp. cf. *F. japonicus* Zone are first attempted to correlated to the fusulinids zone boundaries by the fossil data of this paper.

Concerning the base of *F. charveti* Zone, Ishiga (1991) described, "The base of the zone corresponds to the boundary of the Upper/Middle Permian, on the basis of fusulinids zonation". This correlation was based on data from the Kuma Formation. However, in the Atetsu region, if the *L. imamurai* Zone and *Codonofusiella* assemblage (F) indicate early Late Permian (Sada, 1965), the first occurrence of *F.* sp. cf. *F. japonicus* (R) shows the boundary of the Middle/Late Permian. However, this horizon is correlated to a horizon within the *F. monacanthus* Zone of Ishiga (1991).

Thus, the correlation of the radiolarian and fusulinid zones by the author is inconsistent with that of Ishiga (1991). The reasons of this inconsistency are as follows. *F. charveti* - *F. bipartitus* assemblage, which consists of characteristic species of the *F. charveti* Zone (R), shows limited occurrence in the Kurosegawa, Ultra-Tamba and Tamba-Mino Terranes (Ishiga, 1986b, 1990b). They have not been reported from the Akiyoshi and Maizuru Terranes. Ishiga (1990b) considered that this limited occurrence results from the differentiation of the paleobiogeographic situation in Late Permian time between Ultra-Tamba and Kurosegawa Terranes, and other terranes including the Akiyoshi Terrane. If it is the case, the differences between the correlations of the two zones by Ishiga (1991) and the author is caused from the biogeographic difference. Moreover, the *F. japonicus* Zone (R) has been reported from the *L. kumaensis* Zone (F) in the Maizuru Terrane (Ishiga, 1984). That is, in the Akiyoshi and Maizuru Terranes, the horizon of the first occurrence of *F.* sp. cf. *F. japonicus* or the base of *F. japonicus* Zone (R) corresponds to the boundary of Upper/Middle Permian.

B. Depositional setting of Carboniferous to Permian rocks in the Atetsu region

1. Atetsu Limestone

The Atetsu Limestone is divided into two lithofacies, the Northern and Southern Facies (see Chapter IV). Limestones of both facies rest on basaltic volcanic rocks. According to Takeda and Nishimura (1989), the basaltic rocks of the Ikura Formation (Atetsu Limestone) belong to the alkali rock series. The Akiyoshi Limestone Group has a similar stratigraphic characteristic in the occurrence of the underlying alkari basaltic rocks (Hase and Nishimura, 1979), age, and fossil fauna. It is inferred that the Akiyoshi Limestone Group accumulated on the basaltic pedestal of an isolated oceanic seamount which was widely encircled by coeval deep sea pelagic sediments (Kanmera and Nishi, 1983). The Atetsu Limestone was probably deposited at the same setting of the Akiyoshi Limestone Group.

The limestones are characterized by the lack of the terrigenous input, and a shallow warm condition indicated by fossil constituents, such as fusulinids and corals. The difference of the two lithologies, the Northern and Southern Facies, is most obvious in the lower part of the Atetsu Limestone (Carboniferous Nagoe and Kodani Formations; see Chapter IV). Sakamoto (1991MS) reconstructed the sedimentary environment of the Atetsu Limestone based on petrological observation of limestones of more than 800 thin sections. According to him, the sediments of the Southern Facies are the basal tuffaceous limestone conglomerate, succeeded by oolitic sediments and sediments abounding in skeletal materials. The oolitic sediments seen abundantly in the Southern Facies, were only deposited during Carboniferous. Whereas the Northern Facies limestones were mostly clastic limestones embedded sponge spicular chert. Many Carboniferous limestones formed under high energy environment were found. From these facts, and distribution and thickness of the Carboniferous limestones, Sakamoto (1991MS) presumed that the center of the reef complex situated in Hanagi area, at the southern end of the Atetsu region, and from there the reef complex was later spreading radially. If his opinion is correct, the (southern) half of the reef complex was missed. In Permian time, carbonate depositional area was largest as inferred from the distribution of the Permian limestones. From their lithology, the Northern Facies limestones were probably deposited on slope and the low-laying portion of the basin, while the Southern Facies limestones were mostly deposited at lagoon condition (Sakamoto, 1991MS). Lack of fusulinacean zone between the Kodani and Shoyama, and the Iwamoto and Maki Formations (Sada, 1965) indicates the possibility of subaerial exposure of the reef complex. The limestones of the Maki and Terauchi Formations represented by limestone breccia and limestone conglomerate, thus the

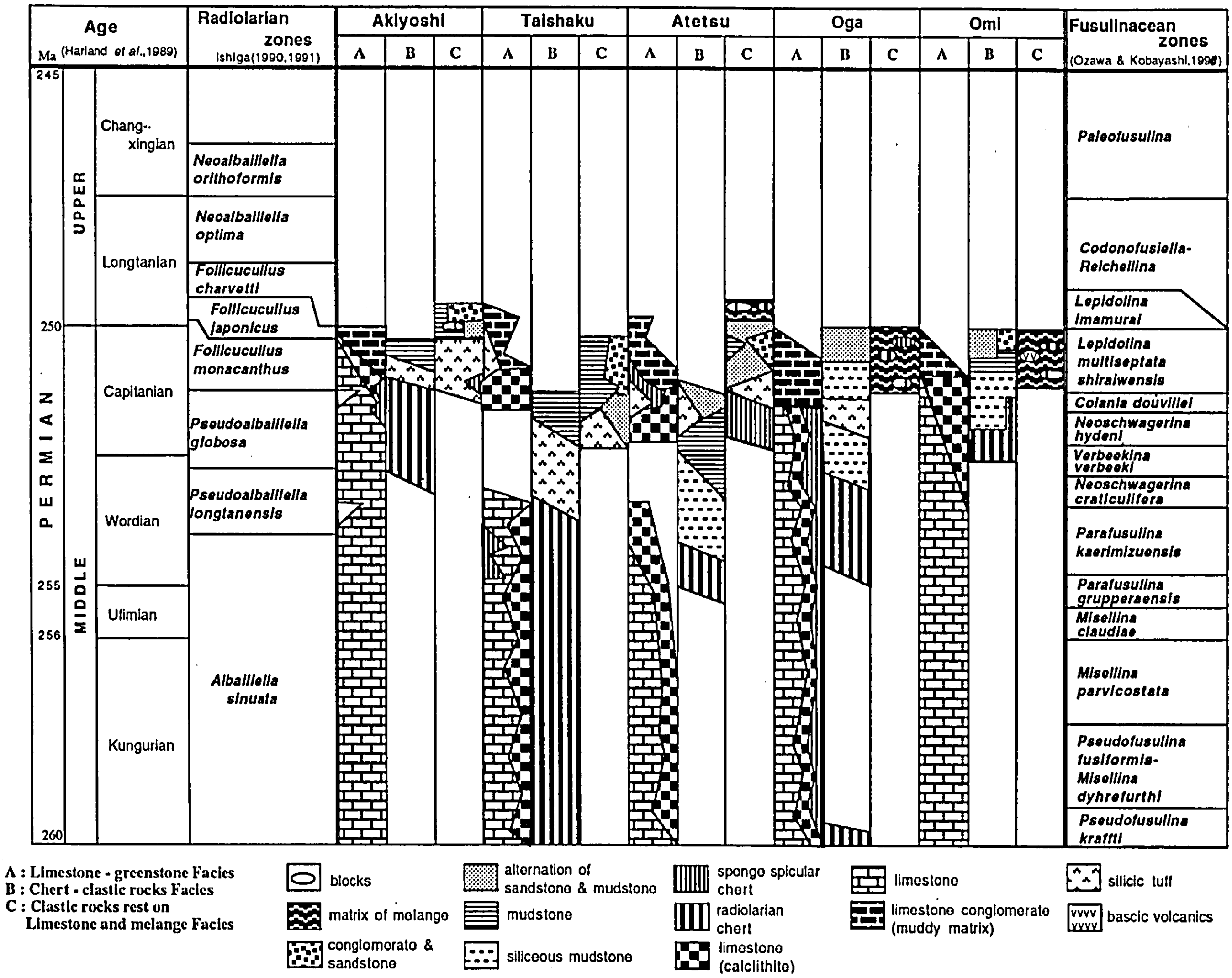


Fig. 42 : The Middle to Late Permian generalized and reconstructed columnar sections of the three lithofacies (A : carbonate facies, B: siliceous to terrigenous clastic rock facies, C: clastic rocks rest upon the limestone and melange facies) in each area. See the text for discussion. Refer to the text for data sources.

depositional environment of the reef complex during Middle to Upper Permian time could not be reconstructed.

In summary, the Atetsu Limestone represents an organic reef complex which is divided into center of reef and forereef, that rests upon a basaltic pedestal in an open-ocean setting.

2. Fuyori Type

The Fuyori Type is characterized by a succession of chert and basaltic rocks in the lower part, siliceous mudstone and mudstone in the middle, and the upper part including sandstone and alternating beds of sandstone and mudstone. Thus, the type generally shows the upward-thickerning and coarsening sequence.

The lower part of radiolarian chert and basaltic rocks are very fine-grained and generally biogenic and not terrigenous. Moreover, chert sequences of the same age and lithology are found in several areas in the Akiyoshi Terrane. This represents that the lateral expansion of depositional environment of the chert was extensive as a pelagic open-oceanic basin. Sano and Kanmera (1988, 1991a, b, c, d) reconstructed that the depositional setting was an open ocean floor located on lower flanks of a sea mount.

The chert is conformably overlies by fine-grained terrigenous clastic rocks of the middle part. In deep on a forearc basin, fine-grained silicic tuff derived from an active volcanic arc as secondary turbidite deposits (Tokuoka *et al.*, 1988). Such a depositional process can form the intercalation of siliceous and fine terrigenous sediments.

The middle mudstones are covered by coarse-grained clastic rocks of the upper part. This gradual vertical change of lithology has been considered diagnostic of ancient trench-fill deposits (Moore *et al.*, 1982; Lash, 1985; Isozaki *et al.*, 1990; etc.) and this succession can be recognized in several areas of deferent terranes. This lithological change indicates the migration of depositional sites from an open-ocean realm to a trench area caused by subduction of an oceanic plate. Thus, this succession is called as the oceanic plate stratigraphy (Isozaki *et al.*, 1990; Isozaki and Maruyama, 1991).

3. Terauchi Type

The two facies of the "Northern" and "Southern" Terauchi Formations conformably overlie the Atetsu Limestone. The lithologic succession of the formation, especially one in the "Northern" Terauchi Formation shows a coarserning upward sequence from silicic tuff and spicular chert through mudstone to sandstone. The property of limestone conglomerates embedded within the lower member of the "Northern" Terauchi Formation and the lower part of the "Southern" Terauchi Formation consists of different aged limestone clasts. The clasts are various in size, poor sorting, disorganized, densely packed, and angular (see Chapter IV). These features indicate that limestone conglomerates have a debris flow origin. These flows probably came from limestone mass to the mudstone depositional site.

Sano and Kanmera (1991a, b, c, d) described details in the macroscopic and microscopic properties of the limestones of the Akiyoshi Limestone Group, Akiyoshi Terrane, and they are recognized three rock types; broken limestone, type A limestone breccia, and the type B limestone breccia. Redeposited limestones, which are embedded in the Tsunemori scaly mudstone, were described as type B limestone breccia, and associated with limestone debris-crowded rock, limestone conglomerate, and limestone sandstone. Comparison the properties between the rocks of the Atetsu region (this study) and those of Akiyoshi region Sano and Kanmera (1991a, b, c, d), makes the following correlation possible. The "massive" limestone and calclithite of the Maki Formation, and limestone conglomerate of the Terauchi Formation are safely correspond with the type A limestone breccia, type B limestone breccia, and limestone debris crowded rocks and limestone conglomerate, respectively. And the Terauchi Formation also contains limestone sandstone and/or calcareous sandstone.

Sano and Kanmera (1991d) considered that decreasing in size of limestone clasts from the type A limestone to limestone sandstone indicate trenchward sediment-gravity flows. In the Atetsu region, lateral change of the clast size is unclear, whereas the vertical change is rather clear. The difference in this facies change was probably due to difference in the collision and accretion mechanisms of sea mounts between Akiyoshi and Atetsu.

Sakagami and Miyama (1988) mentioned that limestone conglomerates may be contemporaneous with the surrounding sediments and were deposited as intermittent turbidite flows.

The silicic tuff layers in clastic carbonate and terrigenous rocks commonly show graded bedding of a gravity flow origin (probably turbidite).

In Summary, coarse terrigenous material could not reach the depositional site in the beginning, and only very fine material such as volcanic ash was accumulated with carbonate debris derived by gravity flows came from limestone mass on a seamount. The subsequent landward movement of depositional site caused terrigenous input upon a seamount of by turbidity current from landside.

4. Taniai Type

The formation mechanisms of the Taniai type are probably various. The Taniai Type contains exotic blocks of oceanic materials (limestone, MORB type basic volcanic rocks, chert) in terrigenous mudstone matrix. The mechanism of mixing of oceanic materials in terrigenous matrix has been discussed for a long time, accompanied by the proposal for several models. They are a sedimentary mixing at trench, off-scraping at shallow depth, underplating, etc. The Taniai Complex is characterized the sheared mudstone matrix including a large volume of oceanic materials which are correspond to the relatively deeper part of the oceanic plate (MORB lava and metagabbro). From the facts, the Taniai Complex was formed at a relatively deeper level of a subduction zone.

On the other hand, the Yotsuune Complex includes a large volume of non-metamorphosed limestones. Okamura and Yamazaki (1987) and Yamazaki and Okamura (1989) has a new idea regarding the origin of melanges on the basis of observation of the modern accretion wedge around Japan. They assumed that an accretionary wedge and slope deposits fall down behind the subducting sea mount, and mixed with the fragments of seamount. The Yotsuune Complex, therefore, probably deposited on behind the subducting sea mount.

The Kamiya Complex is conformably overlies the "Northern" Terauchi Formation, which regards as the coverings on the subducting sea mounts. Therefore, the Kamiya Complex is probably formed at land side of a trench wall and the accreted oceanic material fallen down along the wall.

C. Collisional and accretional events of the Paleo-Atetsu Seamount

From the reconstructing of the depositional setting of the Carboniferous to Permian rocks in the Atetsu region, the collisional and accretional mechanisms of both oceanic and terrigenous materials, and deformation processes related the events are discussed.

A modern analogue of the subducting seamount is observed in the Daiichi Kashima Seamount which has colliding against the Japanese Islands in the Japan Trench (Nakamura *et al.*, 1987). In the case, block faulting tilted trenchward are observed in the seamount. Yamazaki and Okamura (1987) and Okamura and Yamazaki (1989) are also reported the subducting seamounts at the Kuril Trench and the Nankai Trough around Japan. According to them, seamounts beneath the inner trench slopes have preserved magnetization showing reasonably consistent directions, which suggests that the subducting seamounts have roughly kept their original shapes. Limestones and greenstones of seamount origin are commonly observed in the ancient accretionary complexes. However, an accretion mechanism of an ancient seamount and associated oceanic sediments has not been fully examined and discussed. Moreover, it is little documented and discussed what kind of events did happen during collision and accretion of a seamount. Recently, Sano and Kanmera (1991a, b, c, d) described the broken limestones of various textures formed by collapse of seamount, and they are also discussed the collisional process of the Akiyoshi reef complex in the Akiyoshi Terrane.

The geotectonic history of the Akiyoshi Terrane rocks in the Atetsu region from the view points of collisional and accretional events of a seamount is discussed. This discussion is based on radiolarian and fusulinacean biostratigraphies in the Atetsu region, previous ideas of the

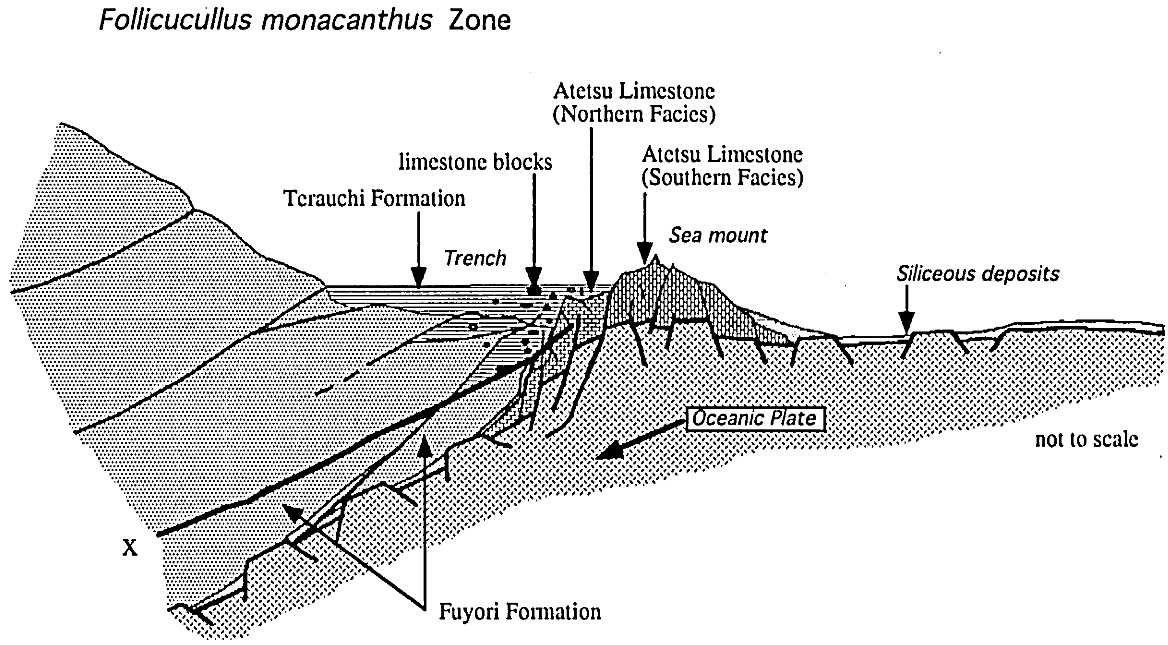


Fig. 43 : A diagram showing the collision and accretion events of the Paleo-Atetsu Seamount. In *Follicucullus monacanthus* Zone (Stage 3; late Middle Permian). A X mark shows the fault bounded the Atetsu Limestone and the Fuyori Formation. See the text for discussion.

collisional process of the reef complex, and following two conditions:

(1) The age of the boundary between underlying chert (pelagic sediments) and overlying mudstones (terrigenous clastic materials) indicates the arrival time of the lowest flank of the seamount (here, its site is called as carbonate front) at a trench.

(2) The age of the upper limit of limestone and lower limit of overlying terrigenous clastic rocks corresponds the arrival time of the seamount at a trench.

From the two conditions, the process of collision and accretion of seamount and related deformation are divided into the following five stages.

(Stage 1) During *Albaillella sinuata* Zone to *Pseudoalbaillella longtanensis* Zone (radiolarian Zone: early to middle Middle Permian), a part of the depositional site of the Fuyori Formation reached at trench. In the same stage (around *Parafusulina kaerimizensis* Zone: fusulinid zone), a seamount rest upon the Atetsu Limestone, which is called here as the Paleo-Atetsu Seamount, far from the trench. Some area of the top of the Paleo-Atetsu Seamount uplifted over the sea-level, because limestone of the *Neoschwagerina Craticulifera* Zone has not been found yet.

(Stage 2) In *Pseudoalbaillella globosa* Zone (radiolarian zone: middle to late Middle Permian), the fine to coarse-grained terrigenous clastic materials covered the pelagic sediments at the trench. However, pelagic sediments were still accumulated in some depositional sites of the Fuyori Formation, especially western areas of the Atetsu region. Because the age of the upper limit of chert in the Fuyori Formation is different in eastern and western areas of the Atetsu region. In the same stage (*Colania douvillei* Zone: fusulinid zone), the Paleo-Atetsu Seamount moved near trench where was supplied fine-grained volcanic ash, because the Southern Facies of the Atetsu Limestone intercalated with alternating beds of silicic tuff and fine-grained calclithite.

(Stage 3 : Fig. 43) In *Follicucullus monacanthus* Zone (radiolarian zone: latest Middle Permian), the terrigenous clastic materials covered pelagic sediments on the carbonate front entirely accreted to accretionary wedge, because the age of upper limit of the Fuyori Formation presumably in this time. In the same stage (*Lepidolina multiseptata shiraiwensis* Zone: fusulinid zone), the front part of fore reef area arrived at trench and provided with voluminous terrigenous materials. Some normal faulting may took place in the Paleo-Atetsu Seamount, because limestone clasts are embedded in terrigenous materials. However, the degree of normal faulting induced collapse of the Paleo-Atetsu Seamount was weaker than that of the Akiyoshi reef complex, because the quantity of collapse deposits representing limestone conglomerate and limestone blocks in trench-fill sediments (Terauchi Formation) is smaller than Akiyoshi.

It is noteworthy that the fault between the Atetsu Limestone Nappe and Fuyori Nappe may be initially formed as a low-angle normal fault. In general, the underlying nappe has a younger accreted age than that of the overlying one. However, in the Atetsu region, the older Fuyori Nappe is tectonically overlaid by the younger Atetsu Limestone Nappe. Thus, this initial low-angle normal fault was probably formed by collision and accretion of the huge voluminous seamount to accretionary wedge.

(Stage 4) In *Follicucullus* sp., cf. *F. japonicus* Zone (radiolarian zone defined in the Atetsu region; refer to Chapter V: early Late Permian), the Paleo-Atetsu Seamount collided to the accretionary wedge and conformably covered by terrigenous materials. However, at the top of the Paleo-Atetsu Seamount, the limestones are still deposited without input of terrigenous materials. The boundary as a low-angle normal fault between upper part of the Paleo-Atetsu Seamount and accretionary wedge becomes growing from trench side to wedge side. The information at back part of the seamount is unclear, because the limestones represents the back part have not been found yet. Some melange suites are formed in this stage. Behind the accreted seamount, for example, the accreted seamount made the slope on land-side unstable. The sediments on the land-side slope were broken and accumulated in the trench. The Kamiya and Yotsuune Complexes include a large scale of chert, limestone and basic volcanic rocks, the origin of the blocks may be interpreted as this way.

(Stage 5) After deposition of the terrigenous materials on the Paleo-Atetsu Seamount, the collisional events were followed by the accretionary process. The fore-reef side of the Paleo-Atetsu Seamount thrust over the central reef. From the continuous distribution of fusulinid zones in whole of the Atetsu Limestone, the destruction of limestones related to accretion of the seamount was not strong. Some parts of melange were formed in this stage at relatively deeper part of the subduction zone, because the Taniai Complex includes the exotic blocks of MORB type lava and metagabbro which represents the oceanic crust. However, most of accreted materials have never been deeply subducted from the total lack of high P/T metamorphic minerals.

Then, the pile nappes and the Nappe boundary bending folds of the Akiyoshi Terrane were generated until the Late Triassic, because the Upper Triassic shelf sediments are unconformably overlies the pile naps.

D. Timing and nature of accretional events in the Akiyoshi Terrane

Based on the correlation of the stratigraphies, the timing and nature of several accreted seamounts in the Akiyoshi Terrane are discussed. Fig. 42 shows the composite columnar sections in selected regions of the Akiyoshi Terrane.

The ages of the carbonate fronts are various in several areas from the condition (1) (see the section C, in this Chapter). For example, The carbonate front is marked in the *Follicucullus monacanthus* Zone in the Akiyoshi region, while it includes in *Albaillella sinuata* to *Pseudoalbaillella longtanensis* Zones in the Atetsu region (Fig. 42). However, the ages of carbonate fronts of several areas in the Akiyoshi Terrane seem to be younger from the Shimomidani (east) to the Akiyoshi (west) direction, with exceptions of the Omi and Nishiki (Naka and Ishiga, 1987; Fig. 42). If it is the case, its lateral younging polarity may be caused by oblique arrangement against to the trench axis.

While the arrival times of the several seamounts at a trench from the condition (2) (see the section C, in this Chapter), they mostly concentrated in the same age. The Atetsu and Taishaku Limestones contains the younger fusulinid zones in the early Late Permian than that of the Akiyoshi and Oga, but the difference is smaller than the age differentiation of the carbonate front in each area.

The relative positions of several seamounts in the Akiyoshi Terrane are shown in Fig. 44, from the composting conditions (1) and (2). If the chain of the carbonate fronts is oblique to the trench, it may indicate that the migrate direction of oceanic plate was oblique to the trench. While the seamounts chain was arranged parallel direction to the trench and the chain was probably oblique to the migrate direction of oceanic plate.

The time gaps between the arrival times of carbonate front and seamounts to the trench are seem to become longer from Akiyoshi to Atetsu (Fig. 44). The reason of the differences of time span between of two presumably due to the topographical shapes of each seamounts.

IX. Summary and conclusion

(1) The Carboniferous to Permian carbonate rock facies in the Atetsu region is represented by the Atetsu Limestone. The Carboniferous to Permian siliceous and terrigenous clastic rock facies divided into three formations and three complexes as follows; the Terauchi Formation (redefined), Fuyori Formation (redefined), Ishiga Formation, Kamiya Complex (newly proposed), Yotsuune Complex. They are grouped into three facies types, the Terauchi, Fuyori, and Taniai Types, from their stratigraphical and structural characters.

(2) The Terauchi Type is characterized by a coherent sequence, encloses remarkable limestone clasts, and conformably overlies the Atetsu Limestone. Further subdivisions are here proposed, by the difference in lithostratigraphy, as Northern and Southern Facies. The Fuyori Type is characterized by a succession of chert in the lower part, siliceous mudstone, silicic tuff, and mudstone in the middle, and the upper including sandstone and alternating beds of sandstone and mudstone. The Taniai Type is a melange suite. The lithology of the various-sized exotic blocks in mudstone matrix are limestone, chert, basic volcanic rocks, metagabbro, etc.

(3) The macroscopic geologic structures can be classified into four fault types and three fold types. Recognition of the Nappe boundary bending folds, indicates that the Carboniferous to Permian rocks in the Atetsu region, Akiyoshi Terrane, formed the major two nappes, the Akiyoshi Limestone and Fuyori Nappes.

(4) Middle to Late Permian radiolarian fossils are found from the Terauchi and Fuyori Formations and chert blocks enclosing the Yotsuune Complex. The morphological characteristics of genus *Follicucullus* are described. Especially, *F.* sp. cf. *F. japonicus* recovered from the Atetsu region may indicate the intermediate forms between *F. monacanthus* and *F. japonicus* described in the Tamba Terrane.

(5) The correlation between the radiolarian and fusulinacean zones are discussed in the Atetsu region. The base of the *F. monacanthus* Zone (radiolarian zone) probably corresponds to the base of *Lepidolina multiseptata shiraiwensis* Zone (fusulinid zone). The first occurrence of *F.* sp. cf. *F. japonicus* (radiolaria) is correlated to the base of *L. imamurai* Zone (fusulinid zone), and indicates the Middle/Late Permian boundary.

(6) An attempt of reconstruction of the depositional setting of the three rock types was done. The Terauchi Type is trench-fill sediments covering directly the colliding seamount. The Fuyori Type corresponds to the oceanic plate stratigraphy, which indicates the depositional site migrate to landward along with the oceanic plate. The processes of forming the Taniai Type are various.

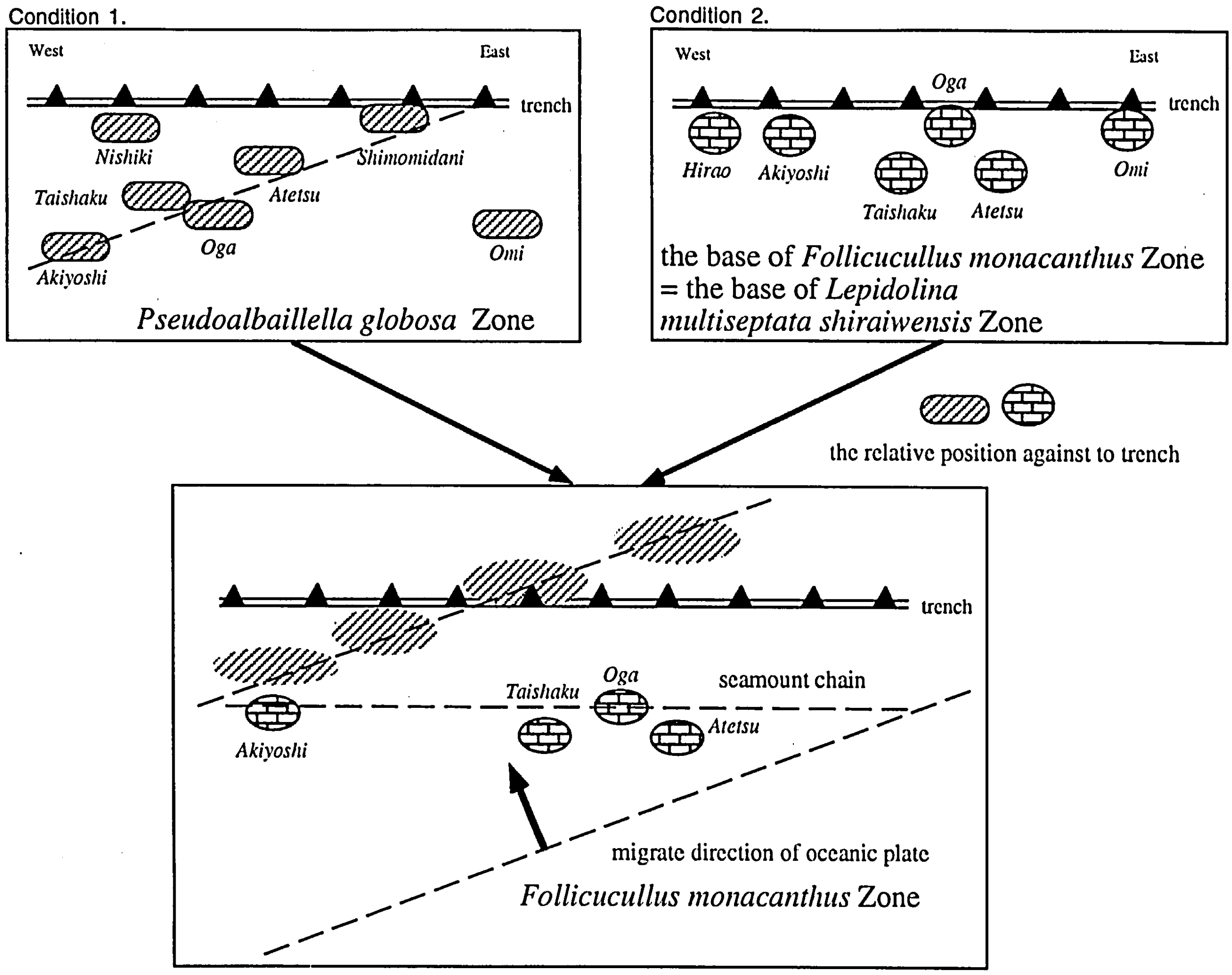


Fig. 44 : The diagrams explain the relatively position of the carbonate front (upper right) and seamount (upper left) on condition 1 and 2, respectively. The lower diagram shows position of the both, compositing from the conditions 1 and 2. See the text for discussion.

Condition 1 : the age of the boundary between chert and overlying siliceous mudstone = the arrival time of the oceanic crust (carbonate front) at a subduction zone.

Condition 2 : the age of the boundary between uppermost limestone and lowermost covered terrigenous clastic rocks = the arrival time of the seamount at a subduction zone.

(7) The geologic history of the Akiyoshi Terrane in the Atetsu region in view point of collisional and accretional events of the seamount is discussed. The seamount capped by the Atetsu Limestone, the Paleo-Atetsu Seamount, collided in the *F.* sp. *F. japonicus* Zone. The Paleo-Atetsu Seamount collided and accreted, but kept its original structure of the front half, and the back half may have been entirely distracted and subducted. The initial form of the fault bounding of the Atetsu Limestone and Fuyori Nappes is probably a low-angle normal fault.

(8) The timing and nature of several accreted seamounts in the Akiyoshi Terrane are discussed. The ages of the upper limit of chert, which indicates the arrival time of the lowest flank of the seamount to the trench (here it called as the carbonate front), have the general younging trend from east to west in the Akiyoshi Terrane. While the arrival times of the several seamounts to a trench, provided from the age of upper limit of limestone and lower limit of Terauchi Type sediments, nearly concentrate in the same age. Thus, the carbonate front chain was arranged at oblique to the trench, while the seamounts chain was roughly arranged parallel to the trench.

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Explanation of Plate

Plate 1

Radiolarian fossils from the "Northern" Terauchi Formation in Terauchi area. All sample localities in Fig. 11.

1-2, 7-10 ,12. *Follicucullus monacanthus* Ishiga & Imoto
Occurrence : 1-2, 8-10, 12 : Loc. 47; 7 : Loc. 392
3-4, 6. *Follicucullus* sp. cf. *F. japonicus* Ishiga
Occurrence : 3-4 : Loc. 392; 6 : Loc. 47
5. *Follicucullus* sp. cf. *F. scholasticus* Ormiston & Babcock
Occurrence : Loc. 168
11. *Follicucullus* sp.
Occurrence : Loc. 47
13. *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto
Occurrence : Loc. 168
14. *Nazarovella* sp.
Occurrence : Loc. 168
Scale bar= 100μm, A= 1-4, 6-8,10-14; B= 5, 9

Plate 2

Radiolarian fossils from the "Northern" Terauchi Formation in Terauchi (Loc. 47) and Hirose (Loc. 1375) areas, and the Maedani Formation in Taishaku area (Loc. T10G). Locality 47, 1375 and T10G are shown in Figs. 11, 14, and 29, respectively.

1, 2, 3, 6. *Follicucullus* sp. cf. *F. monacanthus* Ishiga & Imoto
Occurrence : Loc. 47
4-5, 10-11. *Follicucullus monacanthus* Ishiga & Imoto
Occurrence : 4-5: Loc. 47; 10-11 : Loc. T10G
7 ,12. *Follicucullus* sp. cf. *F. japonicus* Ishiga
Occurrence : 1 : Loc. 1375; 7 : Loc. 47; 12 : Loc. T10G
8-9. *Follicucullus japonicus* var. B Ishiga
Occurrence : Loc. T10G
13. *Pseudoalbaillella* sp. ?
Occurrence : Loc. T10G
14. *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdworth & Jones)
Occurrence : Loc. T10G
15-16. *Pseudoalbaillella* sp. cf. *P. yanaharensis* Nishimura & Ishiga
Occurrence : Loc. T10G
Scale bar= 100μm, A= 1, 3-4, 8-12, 14-16; B= 2, 5-7, 13

Plate 3

Radiolarian fossils from the "Southern" Terauchi Formation in the Kurauchi, Azae and Arasako areas. Sample localities of AC-3 and AC-4, and 1337 and 1396 are shown in Figs. 15 and 18, respectively.

1. *Follicucullus* sp. cf. *F. japonicus* Ishiga
Occurrence : Loc. 1337
2. *Follicucullus* sp.
Occurrence : Loc. 1396
3-6. *Follicucullus monacanthus* Ishiga & Imoto
Occurrence : 3-4 : Loc. 1337; 5-6 : Loc. 1396
7-8. *Pseudoalbaillella globosa* Ishiga & Imoto
Occurrence : 7 : Loc. AC-3; 8 : Loc. AC-4
9-10. *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdworth & Jones)
Occurrence : 9 : Loc. 1396; 10 : Loc. 1337
11. *Pseudoalbaillella yanaharensis* Nishimura & Ishiga
Occurrence : Loc. 1396
12. *Entactinia* sp.
Occurrence : Loc. 1396
Scale bar= 100μm, A= 1-11; B= 12

Plate 4

Radiolarian fossils from the Fuyori Formation in the Atetsu region. Sample localities are shown in Figs. 16 and 18.

1. *Follicucullus* sp. (*japonicus* ?)
Occurrence : Loc. 327A
2. *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdworth & Jones)
Occurrence : Loc. 59
3-9. *Albaillella asymmetrica* Ishiga & Imoto
Occurrence : Loc. 178
10-14. *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto
Occurrence : 10 : Loc. 178 ; 11 : Loc. 152; 12-14 : Loc. 161
15-17. *Pseudoalbaillella* sp.
Occurrence : 15 : Loc. AZ-A; 16-17 : Loc. 178
18A. *Latentifistula* sp.
Occurrence : Loc. 178
18B, 20. *Entactinia* sp.
Occurrence : 18 B: Loc. 178; 20 : Loc. AZ-A
19. *Latentibifistula* sp.
Occurrence : Loc. 178
21. *Pseudotormentus* sp.
Occurrence : Loc. AZ-E
Scale bar= 100μm, A= 1-20; B= 21

Plate 5

Radiolarian fossils and thin section microphotographs from the transition zone between chert and siliceous mudstone in the Yoshii Group, Mihara, Yoshii-cho, Okayama Pref. Sample points show Fig. 30.

1-5. *Albaillella asymmetrica* Ishiga & Imoto
Occurrence : Sample YS1A
6-8. *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto
Occurrence : 6 : Sample YS1A; 7-8 : Sample YS1D
9. *Pseudoalbaillella* sp.
Occurrence : Sample YS1A
10-11. *Latentibifistula* sp.
Occurrence : 10: Sample YS1D; 11 : Sample YS1A

12. *Nazarovella* sp. ?
Occurrence : Sample YS1D
13-14. *Latentifistula* sp.
Occurrence : 13: Sample YS1A; 14 : Sample YS1D
Scale bar= 100μm, A= 1-10, B= 11-14

15. Bedded red chert and red mudstone. Dark parts are mudstone. Rounded and elongated white part are radiolarians and sponge spicules. Sample YS2. Scale bar = 1mm. Plane light.
16. Siliceous mudstone to mudstone. Note the presence of radiolarian fossils (lower right arrow) and detrital quartz grains (center arrow). Sample YS1A. Scale bar = 1mm Plane light.
17. Siliceous mudstone. Note the presence of radiolarian fossil (arrow, *Pseudoalbaillella* sp.). Sample YS1C. Scale bar = 1mm. Plane light.
18. Purple to reddish brown chert. Scale bar =1mm. Plane light.

Plate 6

Radiolarian and conodont fossils from the bedded chert of the Yoshii Group, Chikada, Yuki-cho, Hiroshima Pref. All samples are collected from a great outcrop which is as same as Locs. Y82050, Y82051 by Oho *et al.* (1985) and Sada *et al.* (1985). Sampled horizons are shown in Fig. 31.

1. *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdworth & Jones)
Occurrence : Sample 116A
2. *Albaillella asymmetrica* Ishiga & Imoto
Occurrence : Sample 312M
3-11. *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto
Occurrence : 3-5, 7-8, 10-11 : Sample 116A; 6 : Sample 312M; 9 : Sample 312M
12-13. *Pseudotormentus* sp. cf. *P. kamigoriensis* De Wever & Caridroit
Occurrence : Sample 116A
14-15. *Ishigaum* sp.
Occurrence : Sample 312M
16. *Latentibifistula* sp.
Occurrence : Sample 312M
17. *Entactinia* sp.
Occurrence : Sample 116A
18-25. Conodont gen. et sp. indet.
Occurrence :18, 25 : Sample 312F; 19-20, 22-24 : Sample 312D; 21 : Sample 312P
Scale bar= 100μm, A= 1-11, 14, 17, 21; B= 13, 15, 16, 19, 23-25; C= 12, 18, 20, 22, 25

Plate 7

Radiolarian fossils from the Maizuru and Ultra-Tamba Terranes in south of Oga. All sample localities are shown in Fig. 2.

1-6 ,8. *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdworth & Jones)
Occurrence : Loc. 303A
7, 9-10. *Pseudoalbaillella* sp. aff. *P. longtanensis* Sheng & Wang
Occurrence : Loc. 303A
11. *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto
Occurrence : Loc. 303A
12-13. *Pseudoalbaillella* sp.
Occurrence : Loc. 303A
14-15. *Follicucullus* sp. (*japonicus* ?)
Occurrence : 14 : Loc. 112B; 15 : Loc. 243B

Scale bar= 100μm, A= 1-14; B=15

Plate 8

1-3. Thin section microphotograph of the limestone conglomerate showing fusulinid fossils (*Codonofusiella* spp.) from the "Southern" Terauchi Formation, Matamaru, Azae area. Sample 937. X20. Sample locality in Fig. 18.
4a-b. Thin section microphotographs of lithic wacke type massive sandstone from the "Northern" Terauchi Formation, Terauchi, Terauchi area. Sample 167. a: crossed polars, b: plane light. Scale bar = 1mm.
5. Thin section microphotograph of diamictite from the Kamiya Complex, Terauchi, Terauchi area. Note various sizes and lithologies of angular clasts in muddy matrix. Sample 32. Plane light. Scale bar = 1mm.
6a-b. Thin section microphotographs of spicular chert from the "Southern" Terauchi formation, Matamaru, Azae area. Tube-like structures show tangential sections of the sponge spicules, and small circles are vertical sections. Note that a great deal of sponge spicules are included. Sliced vertical to bedding plane. This sample also contains radiolarian fossils. Sample 936A. Sample locality in Fig. 18. a : crossed polars, b : plane light. Scale bar = 1mm.

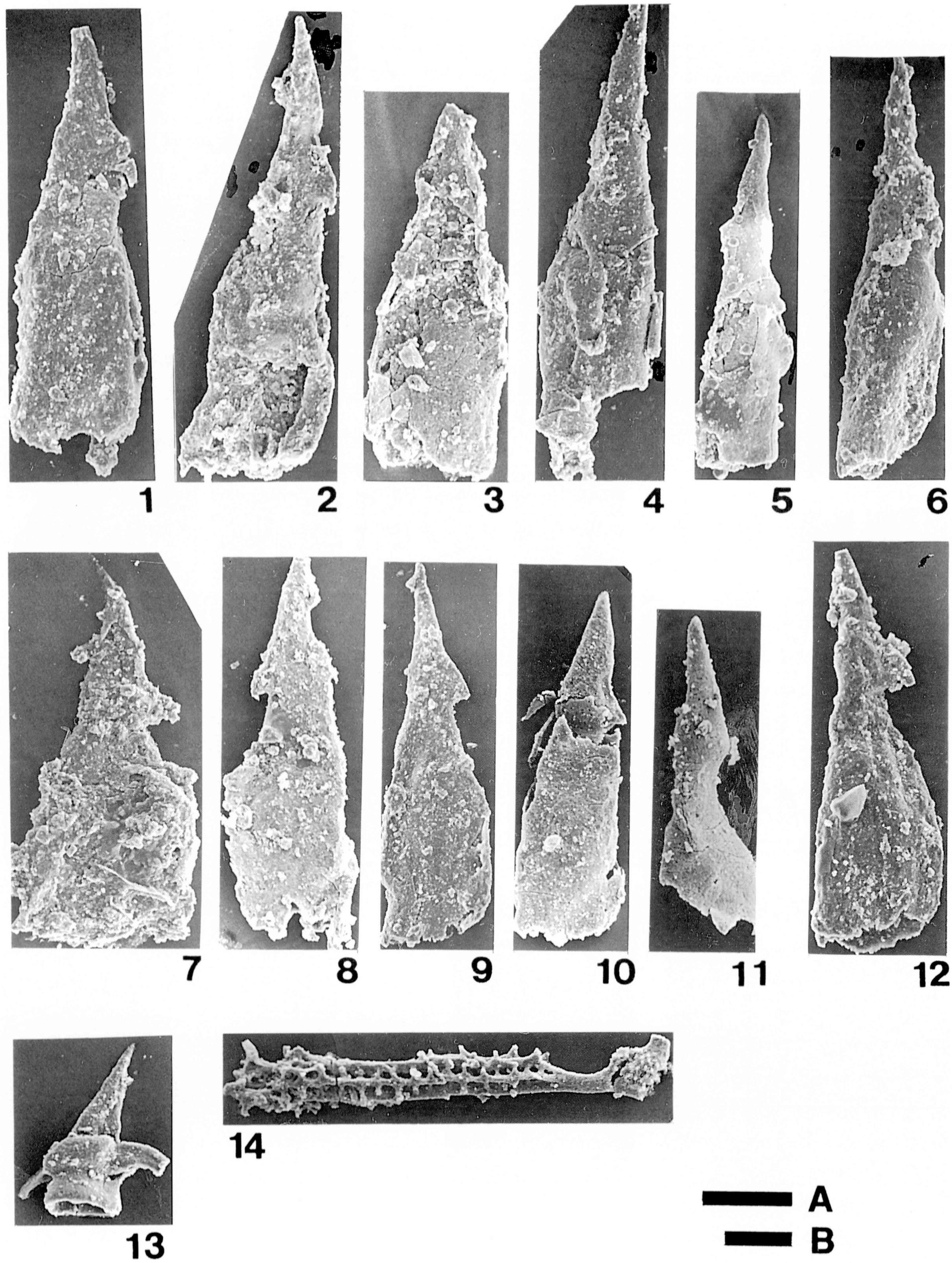
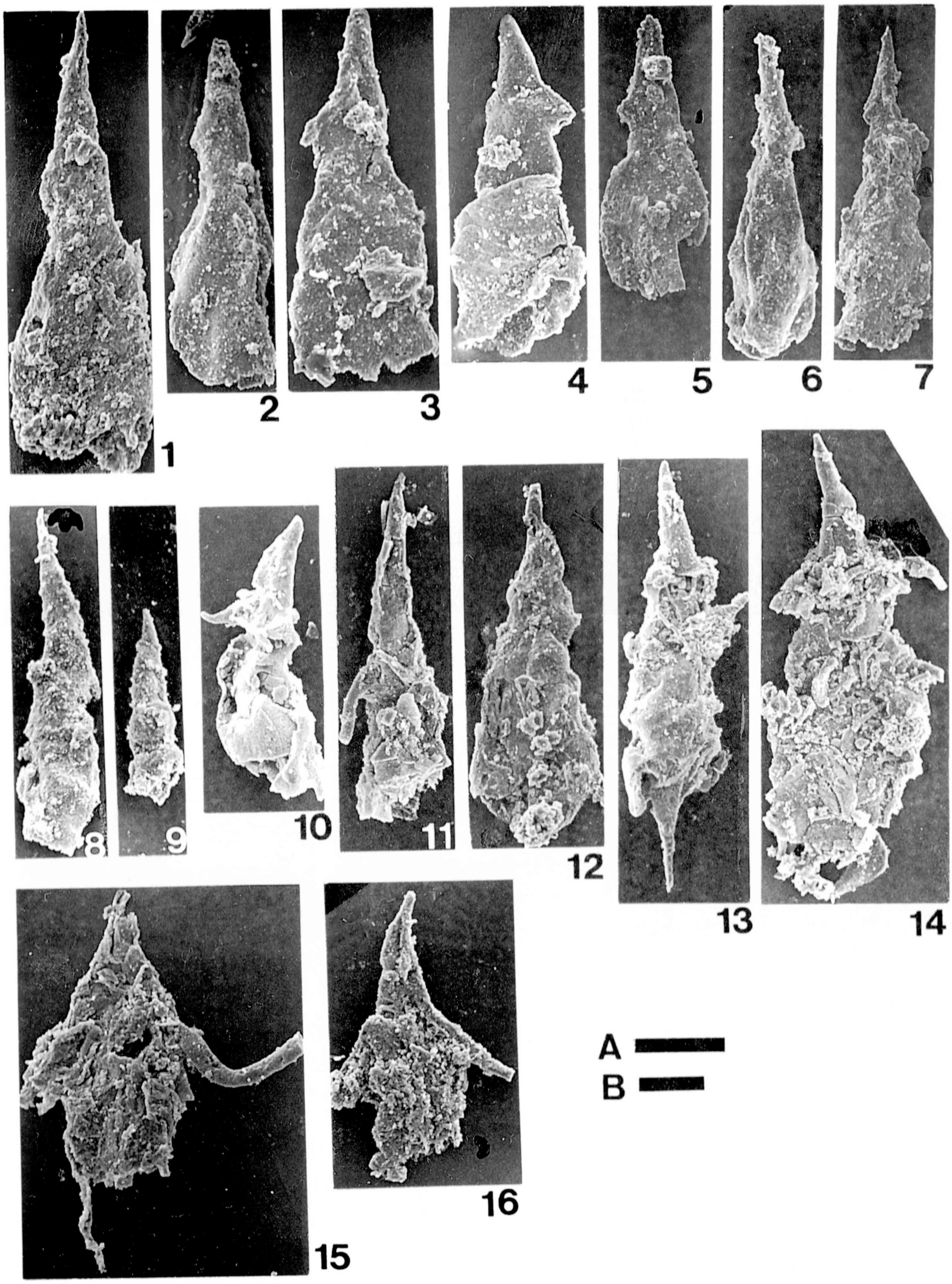


Plate 1



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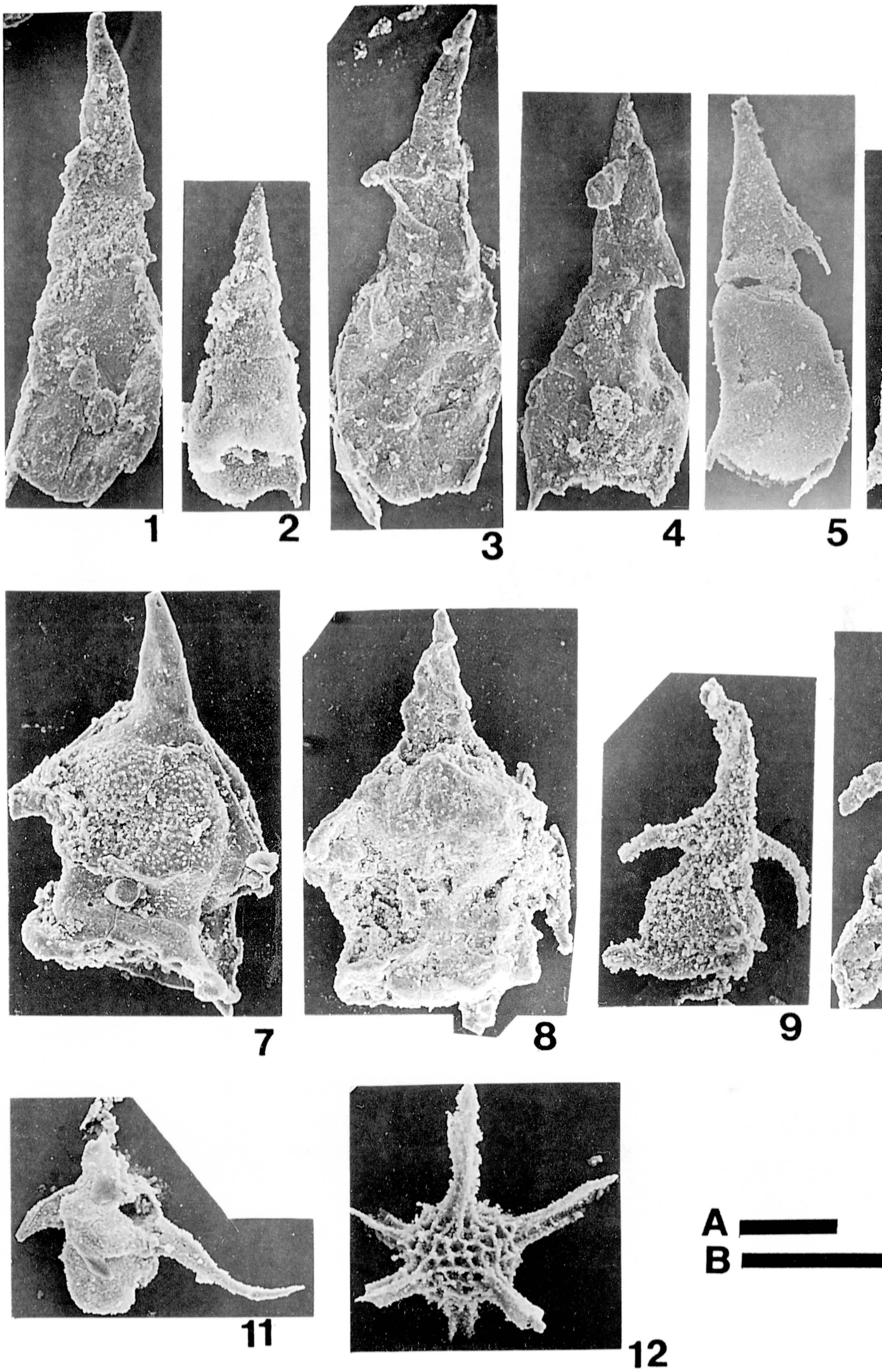

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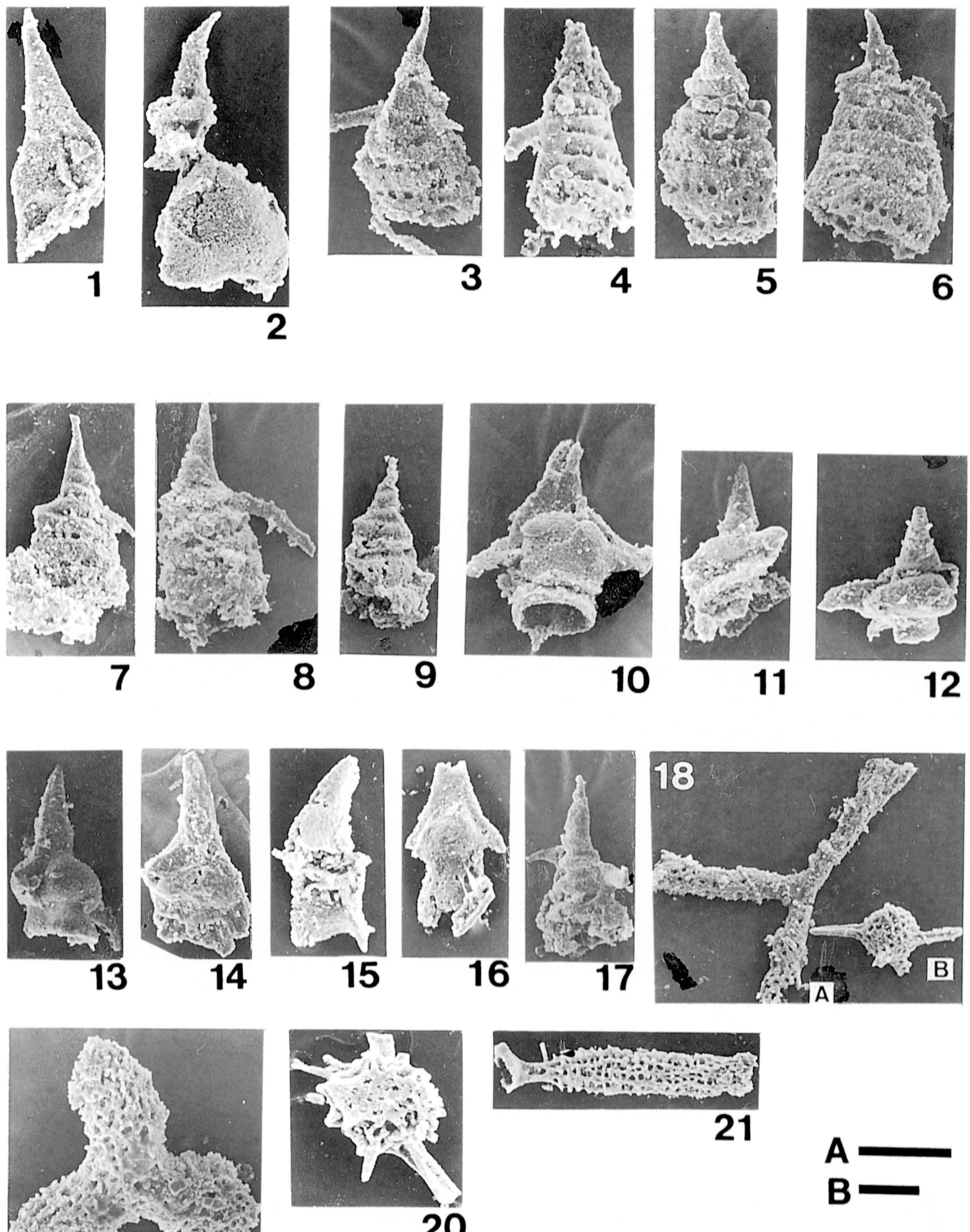

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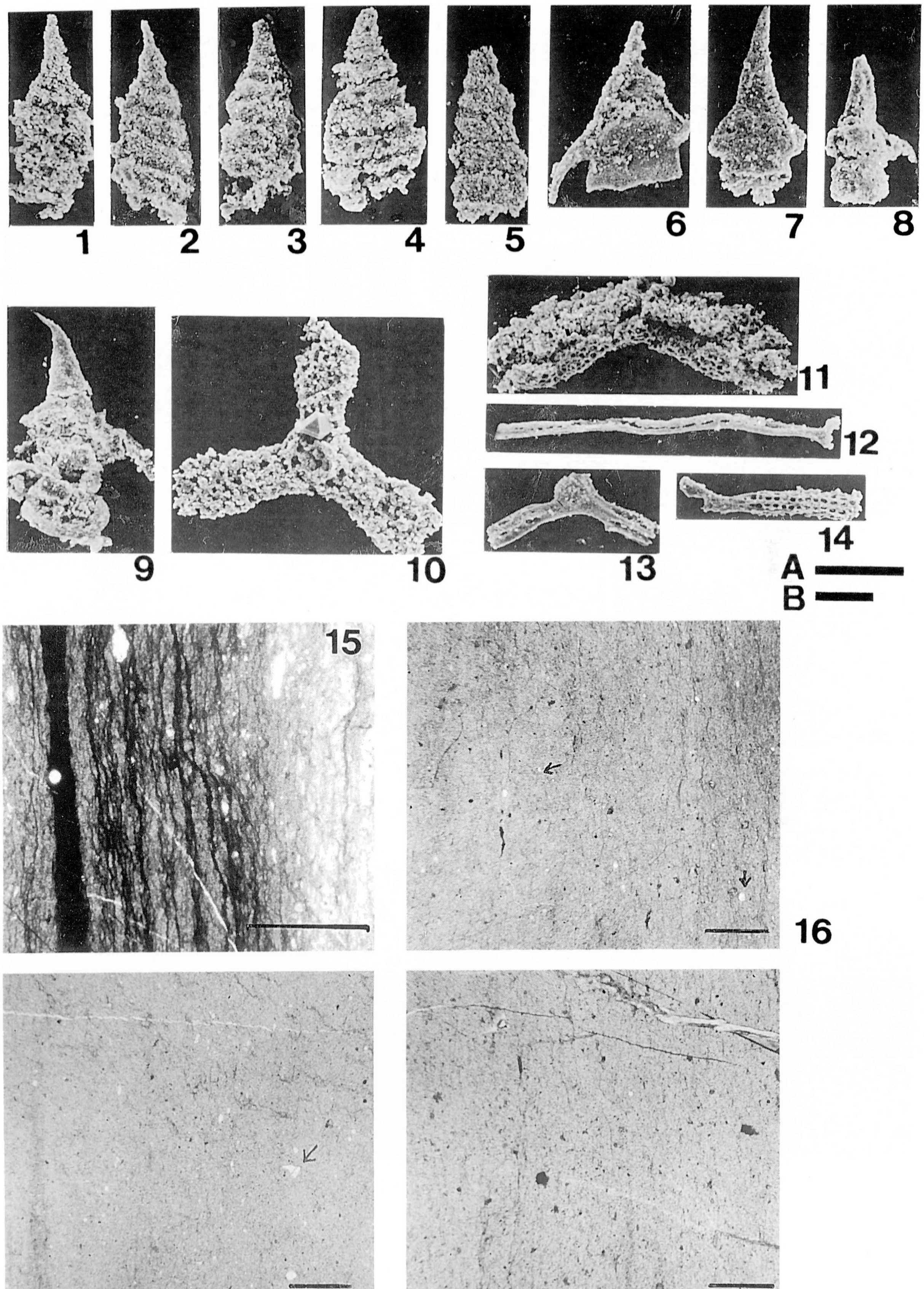

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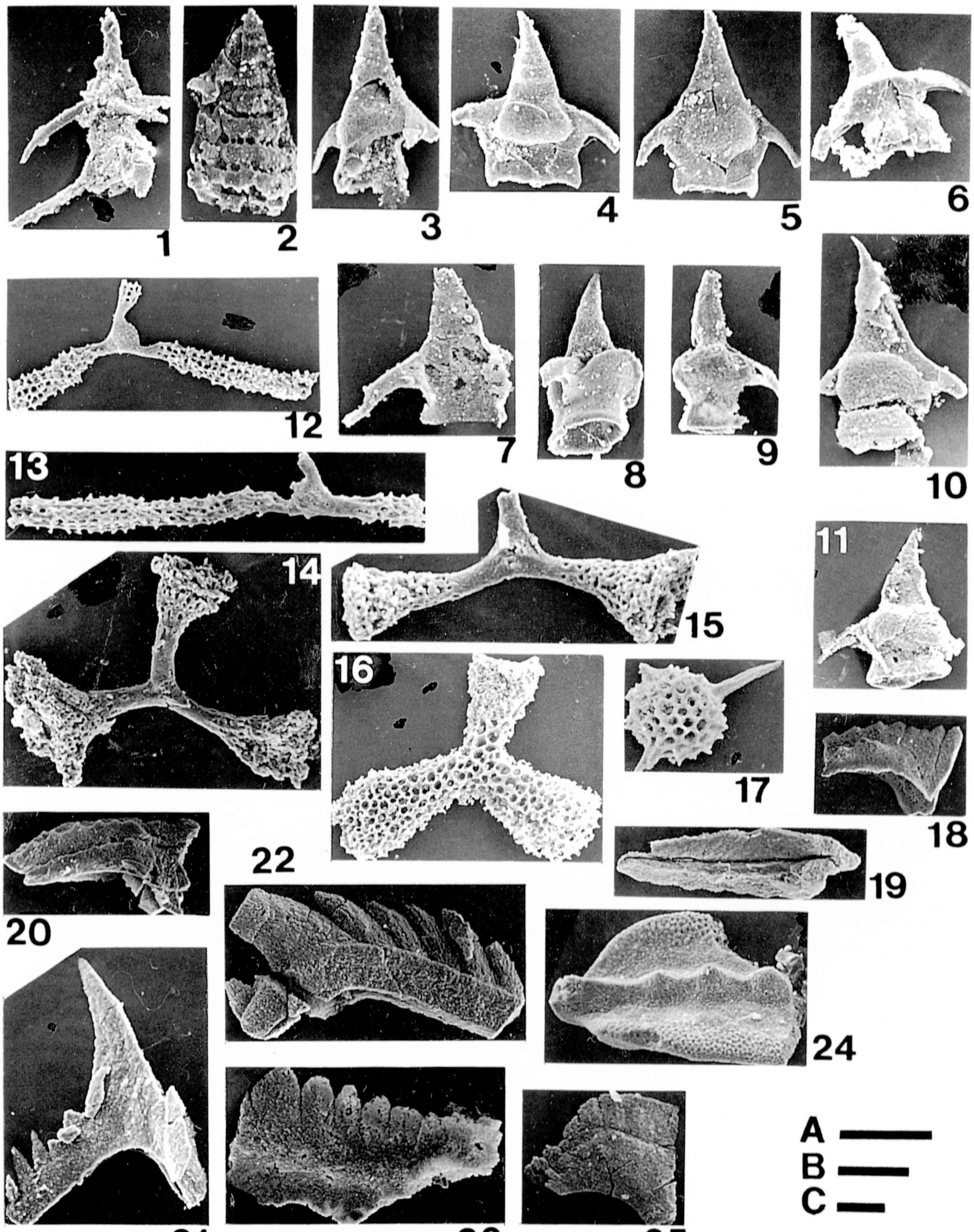

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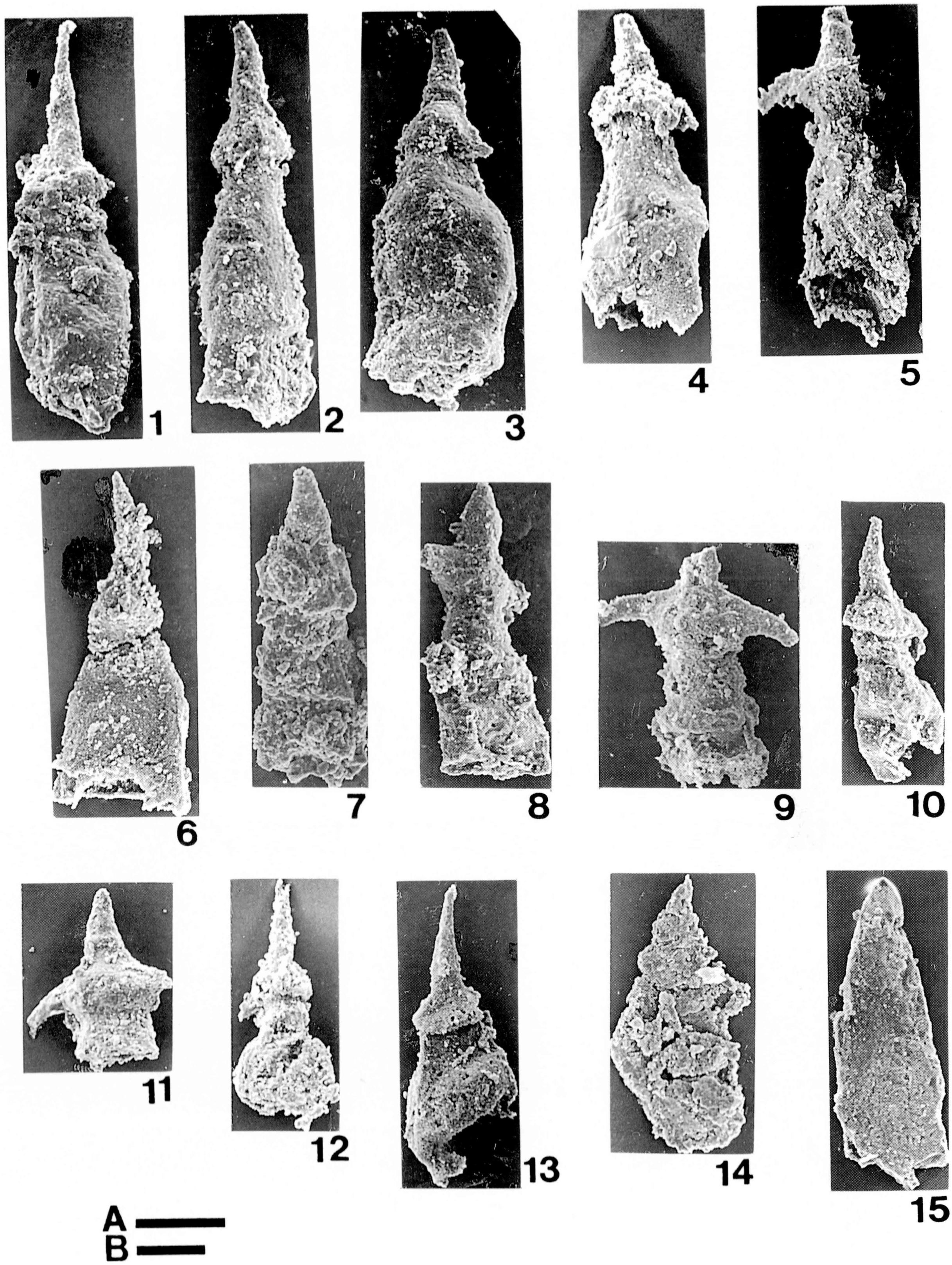
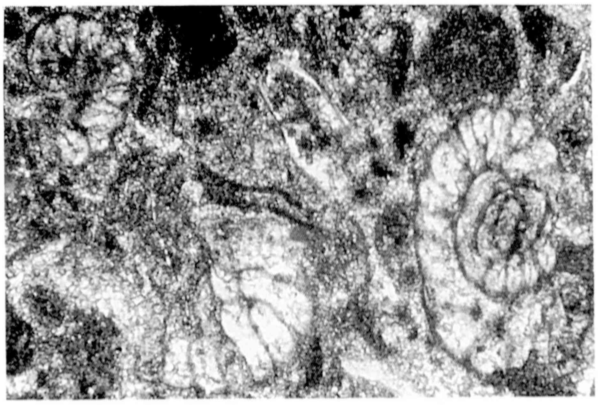


Plate 7



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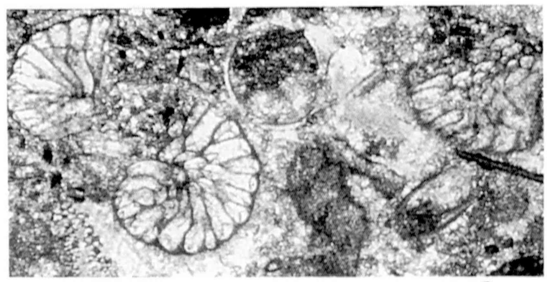

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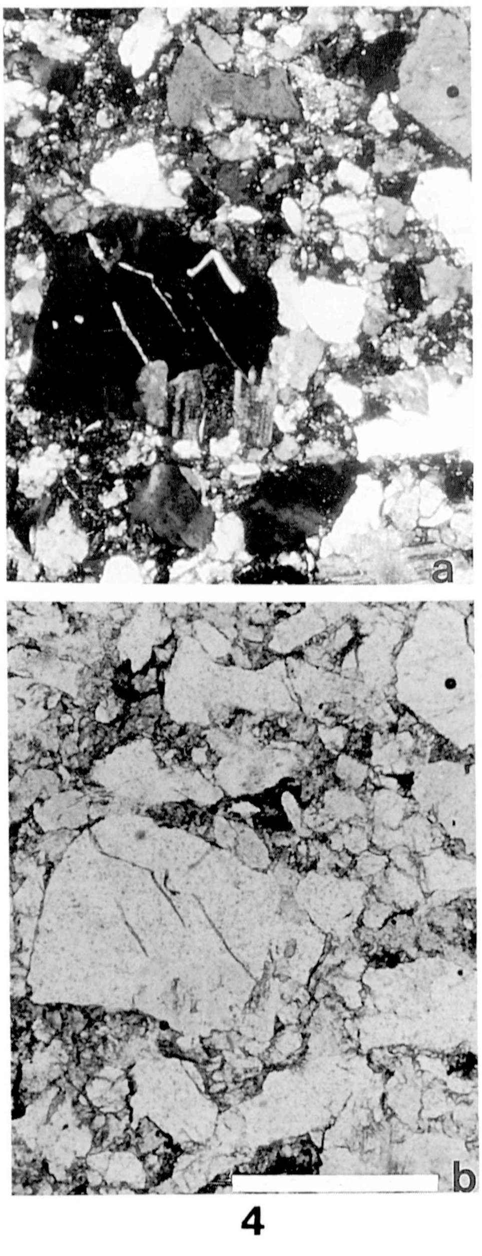

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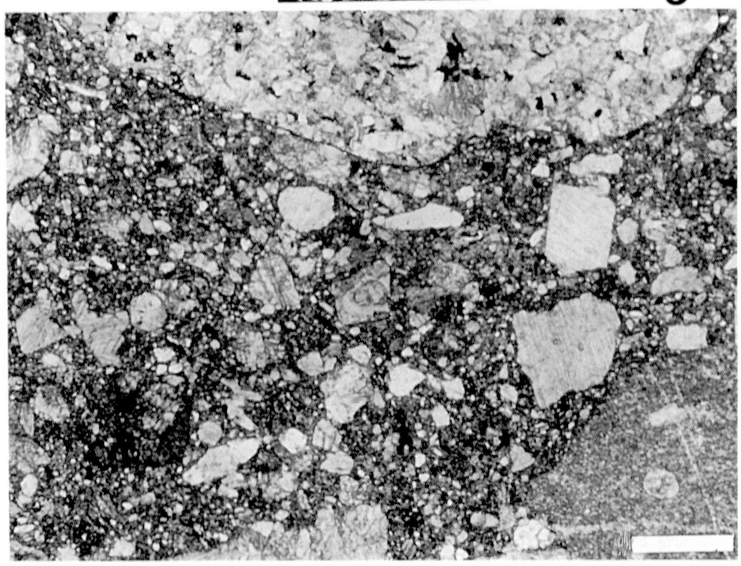

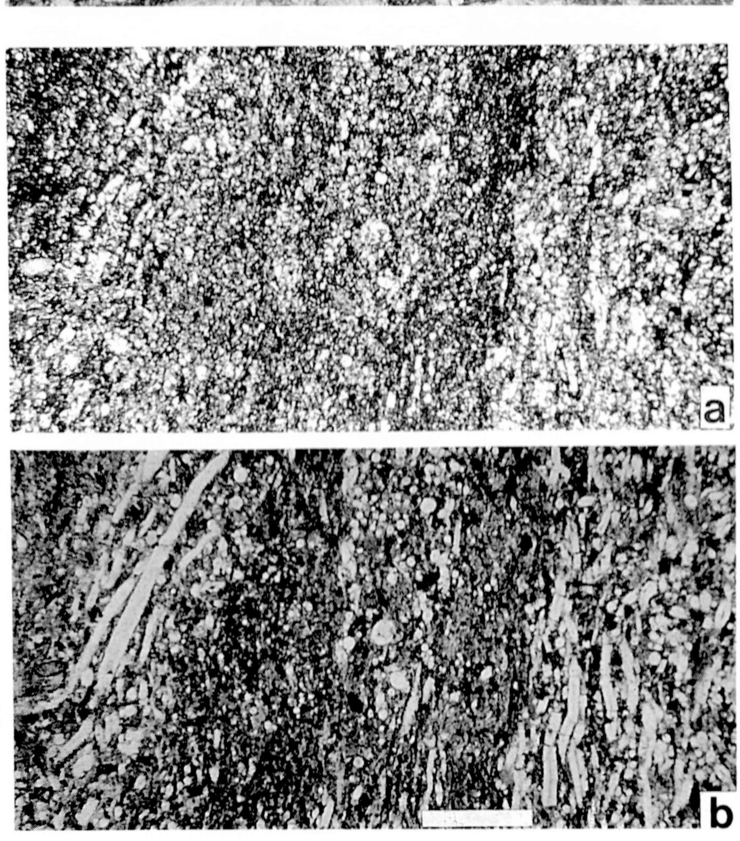

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Plate 8