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Carboniferous Foraminiferal Biostratigraphy of the Lower Part of the Akiyoshi Limestone Group, Southwest Japan

Kazuyuki MATSUSUE*

Abstract

Based on the detailed field survey and laboratory examination, the lower part of the Akiyoshi Limestone Group exposed in the Okubo area is divided into the following 10 foraminifer zones in descending order:

Fusulinella biconica Zone
Profusulinella beppensis Zone
Pseudostaffella antiqua Zone
Pseudostaffella minuta Zone
Millerella yowarensis Zone
Eostaffella ikensis Zone
Eostaffella mosquensis Zone
Mediocris mediocris Zone
Endothyra n. sp. A Zone
Endothyra Zone

These biozones of foraminifers range from the Early Visean of the late Early Carboniferous to the Late Carboniferous Moscovian in European and Russian standard.

According to the distribution of biozones and observation of the laminae, limestones of the Okubo area show a homoclinical structure, dipping south with completely reversed stratigraphical succession, and are essentially successive in both northern and southern slopes along a conspicuous valley of E-W trend in this area. As far as the Okubo area is concerned the normal order of the limestone succession has long been interpreted, and then the result of this study is considerably reverse to the previous recognition.

Foraminifers of the lower part of the Akiyoshi Limestone Group can be divided into two groups by their stratigraphic distributions. Most species of the first group are stratigraphically restricted in the occurrence below the *Millerella yowarensis* Zone. The remarkable faunal change at the level, including the *Eostaffella ikensis* and *M. yowarensis* Zones, is recognized not only within families, such as Archaediscidae and Palaeotextulariidae, but also within genera such as *Tetrataxis* and *Palaeotextularia*.

Despite of the abundant occurrence of various kinds of fossils, there remained some different opinions among researchers on the age determination of

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the lower part of the Akiyoshi Limestone Group. The different interpretations have been caused by various field evidences based on some isolated localities. Therefore the careful faunal correlation among independent locations are strictly required for establishing the summarized biostratigraphy.

Summarizing the biostratigraphic characters on the lower part of the Akiyoshi Limestone Group, it is confirmed that the mid-Carboniferous boundary is apparently recognized at the base of the *Millerella yowarensis* Zone.

I. Introduction

The Akiyoshi Limestone Group is exposed in the western central part of Yamaguchi Prefecture, Southwest Japan, and forms a large limestone plateau measuring 17 km (NE-SW) by 8 km (NW-SE). This limestone sequence spans a long time interval from the Early Carboniferous (Late Tournaisian) to late Middle Permian (Late Guadalupian) and has been regarded as an organic reef complex developed on the basaltic basement of an isolated seamount (OTA, 1968, 1977; NAGAI, 1979, 1985; KANMERA and NISHI, 1983; HAIKAWA, 1986).

SANO and KANMERA (1991a, b, c and d) analyzed the history of genesis and the geologic structure of the Akiyoshi Limestone Group based on the accretionary tectonics. According to their interpretation, the summit of the Akiyoshi seamount was cut and collapsed by its collision with the continental margin, and the process of collapse was well recognized by the existence of a number of limestone blocks in variable sizes in the Akiyoshi Limestone Group. Nevertheless, it is little evident to realize the collapse of limestones in the eastern part of the Akiyoshi Limestone Plateau. Because the foraminiferal biozones are successively traceable both laterally and vertically. The local foraminiferal biostratigraphies in the distributional area of the Akiyoshi Limestone Group are also well correlative with each other.

The limestone is generally light-gray in color without any stratification, except for the basal part where the dark-reddish tuffaceous matters are included. Therefore, the geological structure of this limestone can be analyzed only by discriminating biostratigraphical zones and by mapping them. These biozones have been established on the basis of fusulinaceans, brachiopods, corals, and conodonts. However, there are some different interpretations on the geologic structure and the age of each biozones (OTA *et al.*, 1973; OTA, 1977; YANAGIDA *et al.*, 1977; IGO and IGO, 1979).

The general biostratigraphy of the Akiyoshi Limestone Group was summarized by OTA (1977). He divided it into 21 biozones based on fusulines, corals, and brachiopods. Among them the *Millerella yowarensis* Zone is characterized by the occurrence of abundant fossils of various kinds. But there still remained some important problems to be resolved.

The age determination of the *Millerella yowarensis* Zone is sometimes delicate and critical according to the horizons within the zone. Such being the case correlations among locations have usually been carried out without recognition of exact stratigraphic horizon of each locality.

It has long been required to clarify both stratigraphic and horizontal distributions of fossils and lithofacies in the Akiyoshi Limestone Group. With

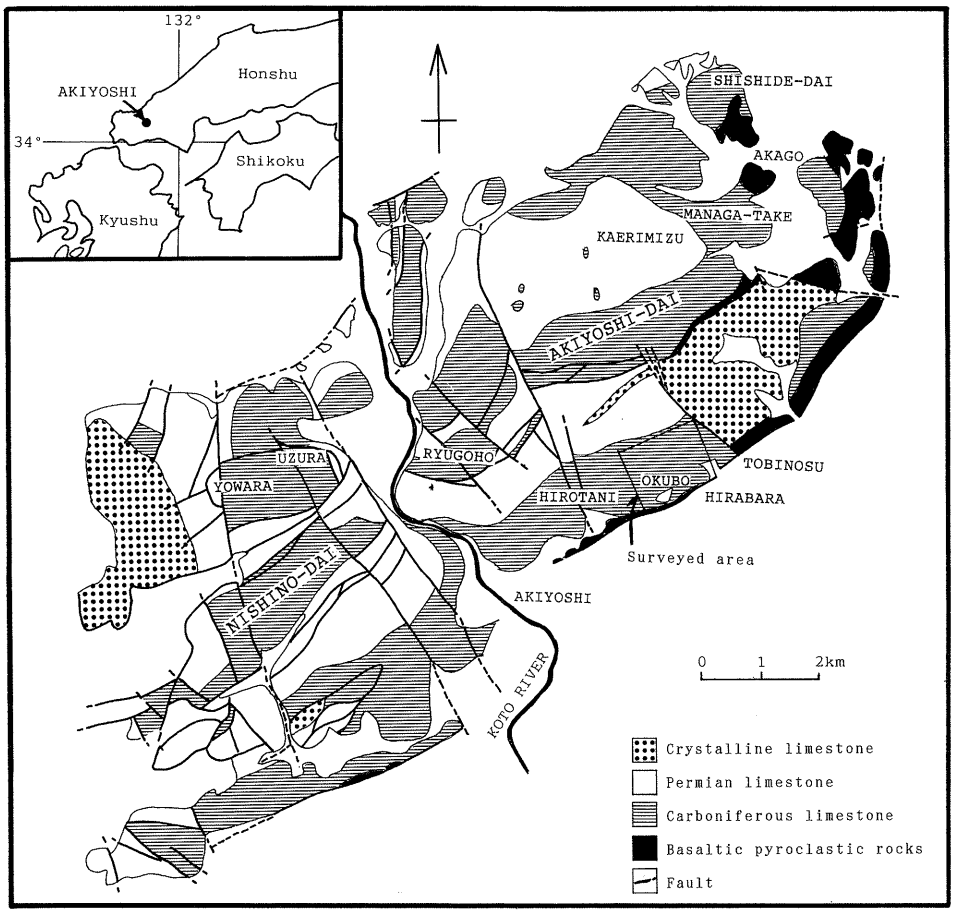

Fig. 1. Index map showing the surveyed area.

this purpose, the author has long focussed the study of the foraminiferal biostratigraphy in the Okubo area (Fig. 1). Because the Okubo area, a part of the southern margin of the Akiyoshi Limestone Plateau, is one of the best fields where the lower part of the Akiyoshi Limestone Group is typically exposed. OKIMURA (1963, 1966) studied the foraminiferal biostratigraphy of the Akiyoshi Limestone Group in the Okubo area. This is the earliest foraminiferal zonation of the Lower Carboniferous in Japan.

In this study several sampling routes were selected in direction of right angle to the extension of fossil zones shown by OKIMURA (1963, 1966) and OTA (1977). Adding them, some routes were also selected parallel to the extension of fossil zones for recognition of lateral changes of bio- and lithofacies. These routes were respectively named MF, MG, MH, MK, ML and OB (Fig. 8).

Detailed field observations and sampling of materials were carried out at each exposure along these routes. About 1500 limestone samples were totally collected at intervals of two to five meters, according to cropping conditions.Two or three unoriented thin sections from each of these samples were prepared, and more than 4000 thin sections were provided for the purpose of

micropaleontological and petrological analyses.

II. Acknowledgments

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Acknowledgment is also due to Dr. Masamichi OTA of the Kitakyushu Museum of Natural History, and Messrs. Akihiro SUGIMURA and Takehiko HAIKAWA of the Akiyoshi-dai Museum of Natural History, for their useful discussion and kind help for field survey, and to Dr. Tetsuo SUGIYAMA of Fukuoka University, Dr. Koichi NAGAI of Ryukyu University, and Dr. Katsumi UENO of University of Tsukuba for their fruitful discussion. Part of this study was financed by grants from the Emeritus Professor Tatsuro Matsumoto Scholarship Fund.

III. General Geology and Geologic Structure

The foraminifer biozones were discriminated from the lower part of the Akiyoshi Limestone Group in the Okubo area as follows in descending order:

Fusulinella biconica Zone
Profusulinella beppensis Zone
Pseudostaffella antiqua Zone
Pseudostaffella minuta Zone
Millerella yowarensis Zone
Eostaffella ikensis Zone
Eostaffella mosquensis Zone
Mediocris mediocris Zone
Endothyra n. sp. A Zone
Endothyra Zone

They are distributed from south to north in ascending order with WSW-ENE trend of general direction of each biozone. A distinctive valley runs in the central part of the studied area from east, Tobinosu, Mito town, to west, Hirotani, Shuho town. In the northern slope of the valley, the biozones become younger as the altitude increases. On the other hand, the opposite succession can be recognized along the slope of the Mt. Gokibuse in the south of the valley (Fig. 2).

In the Okubo area, the basal part of the Akiyoshi Limestone Group is composed of basaltic pyroclastic rocks, and is distributed along the southern margin of this area.The pyroclastic rocks are composed of the reddish tuff and the brecciated porous lava of olivine basalt. They show the same occurrence to those in the Shishide-dai area near the northeastern margin of the Akiyoshi Limestone Plateau (YANAGIDA *et al.*, 1971).

The major part of the Akiyoshi Limestone Group is composed of almost massive, non-stratified limestones, except for the lowest part where they are

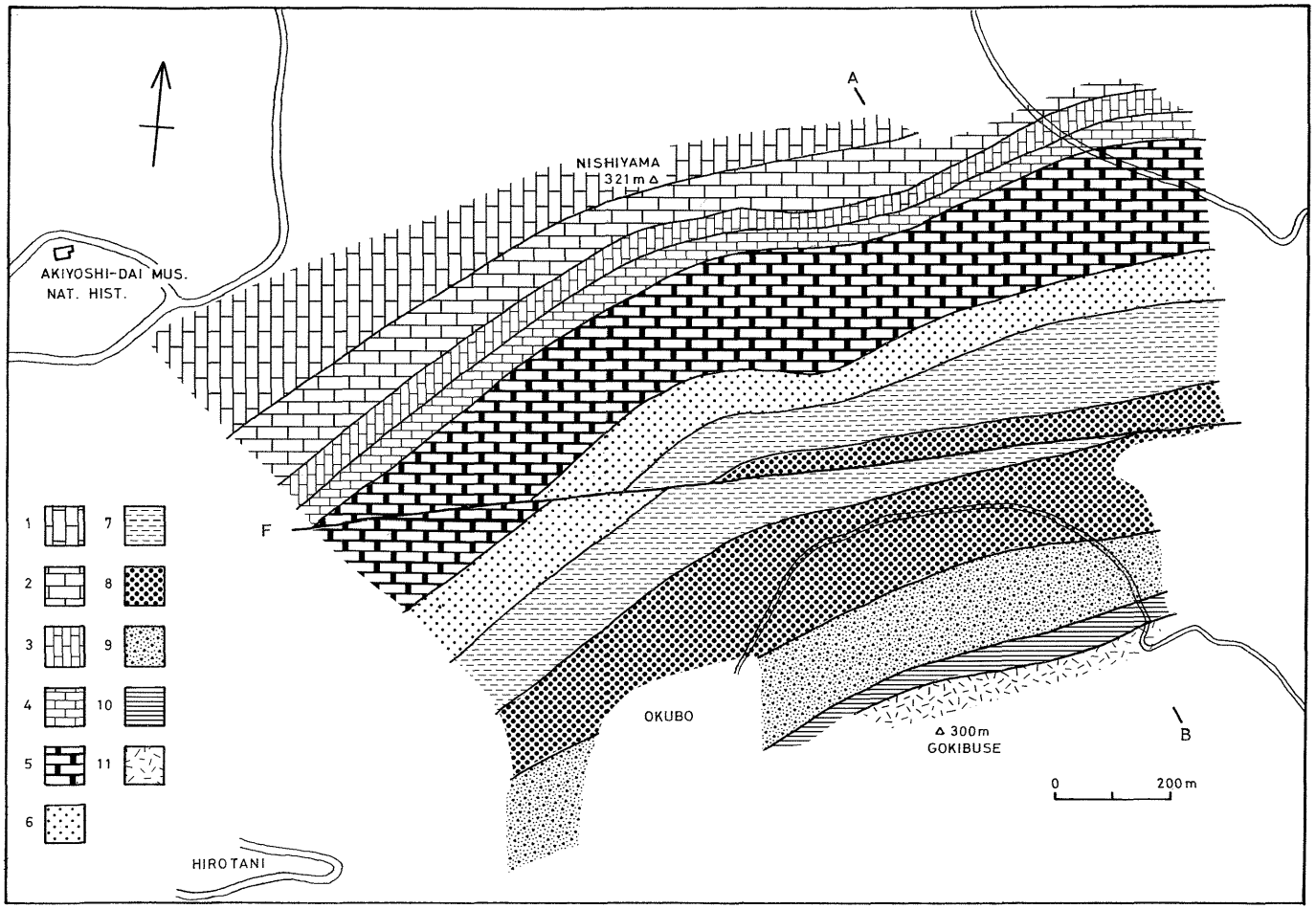


Fig. 2. Geological map of the Okubo area. 1. *Fusulinella biconica* Zone, 2. *Profusulinella beppensis* Zone, 3. *Pseudostaffella antiqua* Zone, 4. *Pseudostaffella minuta* Zone, 5. *Millerella yowarensis* Zone, 6. *Eostaffella ikensis* Zone, 7. *Eostaffella mosquensis* Zone, 8. *Mediocris mediocris* Zone, 9. *Endothyra* n. sp. A Zone, 10. *Endothyra* Zone, 11. pyroclastic rocks.

tuffaceous in texture. In the field, it is quite difficult to divide limestones to any lithostratigraphic units, and to measure the strikes and dips as we can not confirm the bedding plane of limestones.

The geologic structure of the Akiyoshi Limestone Group, therefore, has been presumed mainly based on the inferred strike and dip of limestone beds concluded by the pursuit of the distributions of biozones. In the Okubo area, however, it is difficult to presume the geologic structure from the distribution of biozones, because the general trend of biozones is nearly parallel to the topographic profile. There were various interpretations by many investigators on the geologic structure of this area.

In the northern slope of the valley, the sequence of limestones has been considered by many previous authors to be normal in order. Because the younger biozone is distributed on topographically higher slope. On the other hand, at the Mt. Gokibuse in the highest part on the southern slope of the valley, it has been well known that both tuffaceous limestones and tuffs well reveal the bedded structure, dipping to south.

Taking these evidences into consideration, MURATA (1961) presumed an anticlinal geologic structure along the valley. YANAGIDA and OTA (1964) also regarded the oolitic limestone along the bottom of the valley as the lowest part of the Akiyoshi Limestone Group in this area. Thereafter, OTA (1968) established the *Zaphrentoides* sp. Zone based on corals and brachiopods found from near the boundary of oolitic and tuffaceous limestones.

ETO (1967) studied limestones of this area from the petrographical viewpoint. He confirmed the presence of the southwardly dipping structure both in the south and north of the valley. He interpreted the presence of folding of small and normal orders. However, no record of northern inclination was given in his measurements.

OKIMURA (1963, 1966) examined the biostratigraphy based on the smaller foraminifers in this area. He noticed the oldest foraminifers yielded from the southern limits of the tuffaceous limestone. As the result, he assumed the possibility of the reversed order at least in the south of the valley. IGO (1973) reported conodont assemblages from the tuffaceous to oolitic limestones in and around the *Zaphrentoides* sp. Zone of OTA. He concluded that the limestone successions became younger from south to north as same as the OKIMURA's result.

Comparing with previous interpretations mentioned above, the result of this study is considerably different.

Sometimes the laminae have been observed not only in the field but also in thin sections under the microscope. These laminae are formed by linear arrangement of elongated bioclasts of brachiopods, bryozoans, foraminifers and others. Examination of thin section analysis on the limestone laminae is very useful and it is indispensable to ascertain the geologic structure of massive limestones, like the Akiyoshi Limestone. But the strike and dip deduced from the plane of laminae are not always directly considered to be the bedding plane of limestones. Based on this view point, KAWANO (1967) examined the relation between the strike and the dip obtained from the plane of laminae and those of limestone beds in the neighboring area of the Mt. Managa-take, northeastern part of the Akiyoshi Limestone Plateau. He concluded that the planes by laminae were

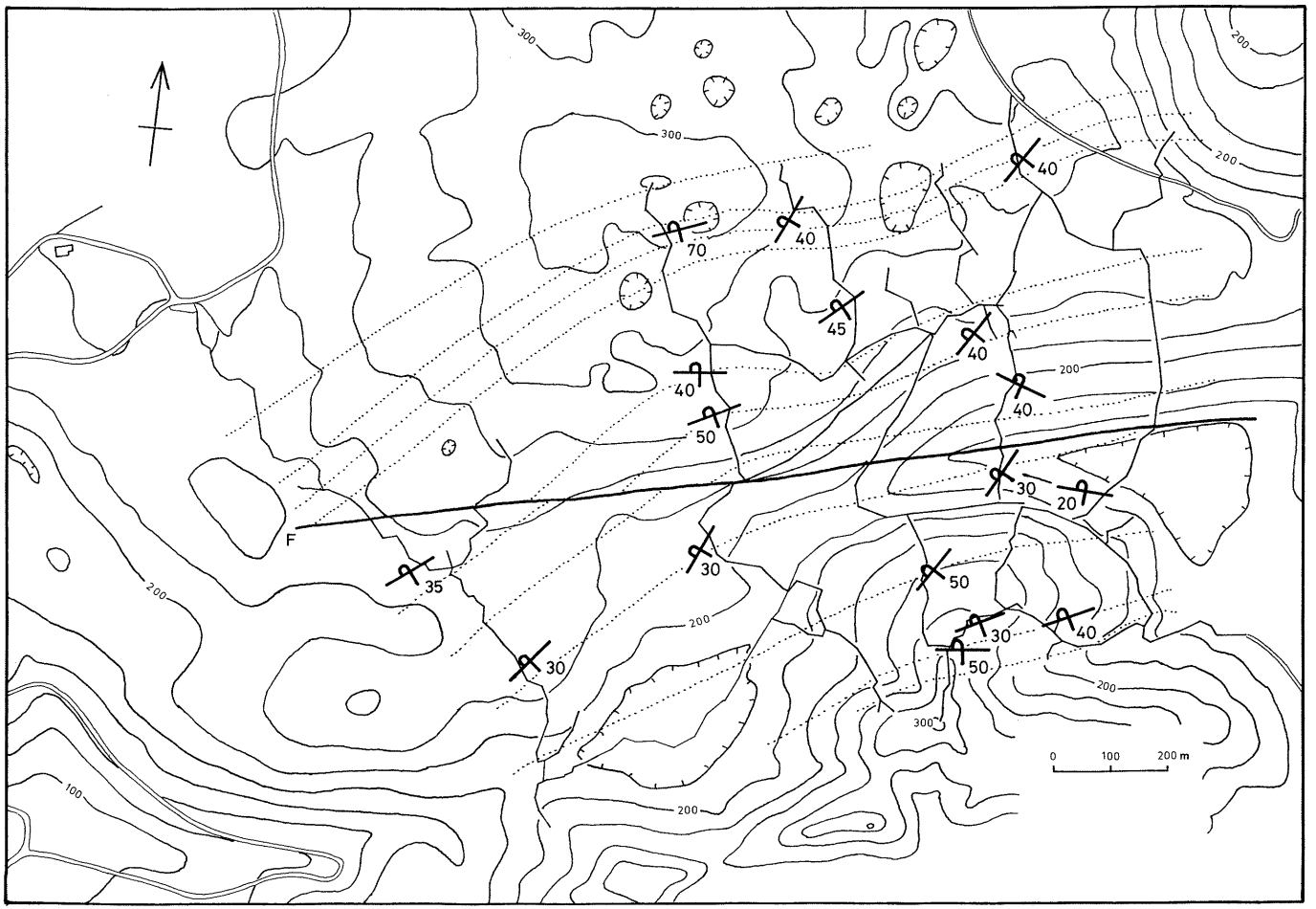


Fig. 3. Map showing the dip and strike measured from laminae of limestones in the Okubo area.

in harmony with the geologic structure presumed by distribution of biozones.

In the Okubo area, laminae are observable not only in the field but also in thin sections under microscope. The author tried to measure the strikes and dips of the planes of these laminae by the clinometer in the field or by the polished surface of oriented samples. The result of measurement is shown in Fig. 3. The strikes by the planes of laminae generally agree to the distributional trend of biozones. This result corresponds to that of KAWANO (1967) in the Mt. Managatake area. It is remarkable that all measured planes of laminae dip to south with some variation within degrees from 20 to 70.

Although it is impossible to confirm the dipping angle of limestone bed by distribution of biozones, geologic structure of the limestone sequence of this area is considered to be almost homoclinally inclined to south, and the reversed order is suggested.

The reversed order is also strongly suggested by depositional evidences. In the lower part of the *Millerella yowarensis* Zone, many disarticulated brachiopod shells are arranged in dipping south with their convex surfaces downward. Moreover, in the upper part of the *Millerella yowarensis* Zone, colonies of chaetetids and stromatolites often show the downward growth in limestones. It is easily considered that these reversed colonies may be referable to the destruction by strong wave agitation. But no evidence of destruction is preserved in these colonies-bearing limestones.

According to the distribution of biozones and measurements of the laminae, the geologic structure of limestones of this area is essentially in harmony with both northern and southern slopes of the valley, and is represented by southward dipping homoclinal structure with completely reversed order (Fig. 4).

According to OTA *et al.* (1973), the southern side beyond a major thrust which runs from east to west in nearly the center of the Akiyoshi Limestone Plateau, is composed of limestone sequence of normal order. The northern side of the thrust, on the other hand, is characterized by completely reversed sequence of limestones. The Okubo area was included in the area of normal order. Moreover, OTA (1968) reported the normal order around the Akiyoshi-dai Museum of Natural History, westward adjacent to the Okubo area. HAIKAWA and OTA (1978) reported the presence of a northern inclined structure in the

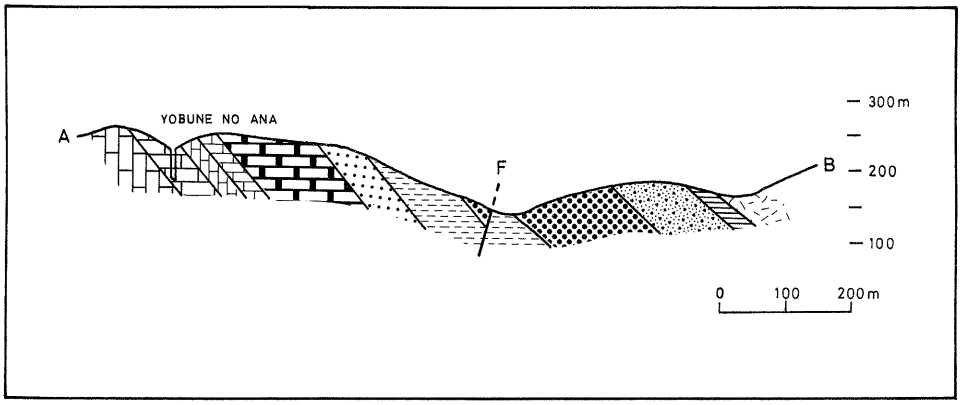


Fig. 4. Geological profile of the Okubo area. A-B line of the section is indicated on Fig. 2.

Tobinosu area, eastward adjacent to the Okubo area. The relation of the geologic structure among this area and the adjacent ones reported as the normal order remains unclear. This is one of the important problems to be solved in future.

IV. Stratigraphy and Lithofacies

The distribution of the lithofacies and the stratigraphic distribution of foraminifers in the Okubo area are shown in Figures 5 and 6, respectively. The foraminiferal assemblages and lithofacies of each biozone are as follows:

(1) *Endothyra* Zone

In the southern margin of the Okubo area, the pyroclastic rocks composed of the porous lava and tuff of the olivine basalt are exposed. The pyroclastic rocks are regarded as the basement of the Akiyoshi Limestone Group in the surveyed area (ETO, 1967; OTA, 1977).

The *Endothyra* Zone is the lowest foraminiferal zone of the Akiyoshi Limestone Group in this area, and directly overlies the pyroclastic rocks. This zone consists of the tuffaceous limestone mainly composed of bioclasts of crinoids in association with rock fragments of the olivine basalt and fine tuff. The tuffaceous limestone is weakly recrystallized and sparsely dotted in thin sections by rhombic or hexagonal crystals of dolomite. Magnesian component of these dolomite must be derived from the volcanics, because no dolomite occurs in any other horizons of the Akiyoshi Limestone Group.

The uppermost of this zone is intercalated by a few beds of reddish tuff, which range from 10 to 20 cm in thickness. These tuff beds yield bioclasts of crinoids, brachiopods, and corals including *Cyathaxonia*.

Only few endothyraceans occur in limestone of this zone and they are too poor in preservation to exactly identify.

(2) *Endothyra* n. sp. A Zone

The *Endothyra* n. sp. A Zone directly overlies the thin, reddish tuff bed, the top of the *Endothyra* Zone. The lower part of this zone is composed of the tuffaceous limestone, as same as the underlying zone. The tuffaceous limestone is reddish or dark greenish in color, and is composed of bioclasts of crinoids in association with corals, bryozoans and brachiopods, and small patches of basaltic tuff. These tuffaceous matters in limestone decrease gradually and upwards. In the upper part of the zone, especially in the western part of this area, the tuffaceous matters are scarcely observed.

The base of this zone is characterized by the sudden occurrence of many kinds of foraminifers in contrast with the underlying zone. *Endothyra* n. sp. A appears at the base of this zone. This species was reported under the name of *Endostaffella* sp. A in previous papers (MATSUSUE, 1986 and 1988).

Besides the name-bearing species, following species appear at the base of the zone; *Endothyra* ex gr. *similis, Endothyra* sp. B (= *Endostaffella* sp. B in MATSUSUE, 1986), *Endothyra* spp., *Planoendothyra* cf. *sigma, P.* sp. A, *Mikhailovella* sp., *Viseidiscus* sp., *Paraarchaediscus* sp., *Tetrataxis* spp., *Palaeotextularia* spp. and *Deckerella* sp.

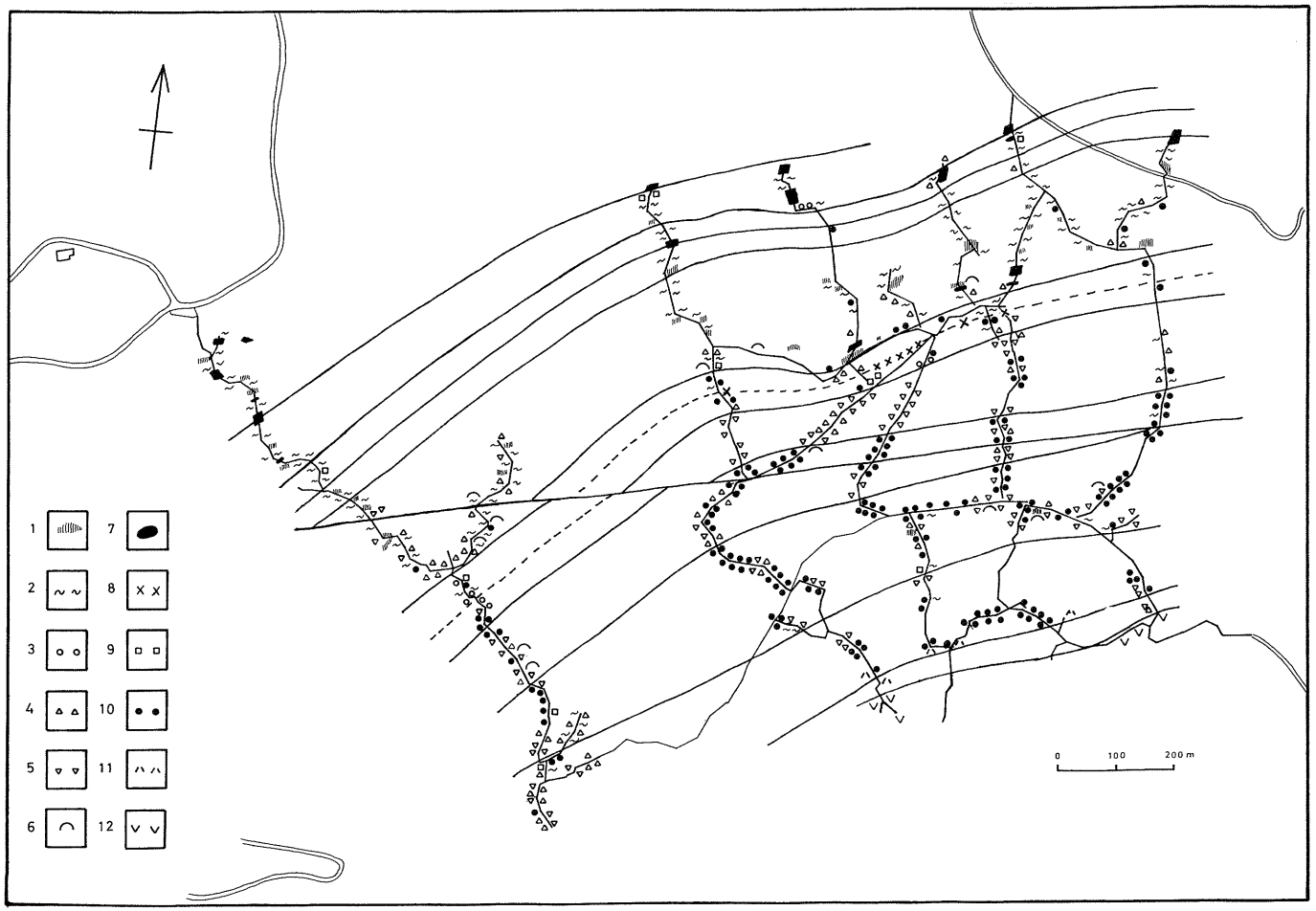


Fig. 5. Map showing distribution of lithofacies with main components in the Okubo area. 1. biolithite, 2. algal limestone, 3. foraminiferal limestone, 4. crinoidal limestone, 5. bryozoan limestone, 6. brachiopod limestone, 7. micrite, 8. distorted oolite, 9. intraclastic limestone, 10. oolitic limestone, 11. tuffaceous limestone, 12. pyroclastic rocks.

Thereafter, *Haplophragmella* sp., *Neoarchaediscus*? sp. B and *Pseudoammodiscus* sp. B appear in the middle part of this zone.

At the Loc. MH227 along the road from Hirabara to Okubo, "the reddish tuffaceous shale" crops out. HASEGAWA (1963) found brachiopods, bryozoans and corals in this shale. MINATO and KATO (1963) described them as follows; *Pleurodictyum dechenia, Cyathaxonia* sp. B, *Nebenothyris hasegawai, Chonetes* sp., *Waagenoconcha* sp., *Neophricodothyris*? sp. and *Pterinopecten* sp. They briefly referred the age of the fauna to the earliest Namurian.

HASEGAWA used the name, "the reddish tuffaceous shale," to all tuff beds in several horizons of the lower part of the Akiyoshi Limestone Group in this area. In present paper, the name, "the reddish tuffaceous shale", is restricted to the shale which crops out at the Loc. MH227. Because other tuff beds are thinly intercalated by the limestones in the lower levels.

The stratigraphic position of "the reddish tuffaceous shale" has been treated by several authors to different levels based on the different interpretations of the geologic structure of this area.

YANAGIDA and OTA (1964) reported some Tournaisian corals and brachiopods, such as *Clisiophyllum, Lonsdaleoides, Zaphrentoides, Syringothyris, Leptagonia* and *Spirifer,* without descriptions from the shale and adjacent tuffaceous limestone. They interpreted an anticlinal structure along the valley, and they considered that "the reddish tuffaceous shale" was the base of the Akiyoshi Limestone Group in this area. Thereafter, OTA (1968) established the *Zaphrentoides* sp. Zone as the lowest biozone of the Akiyoshi Limestone Group on the basis of corals and brachiopods from this locality.

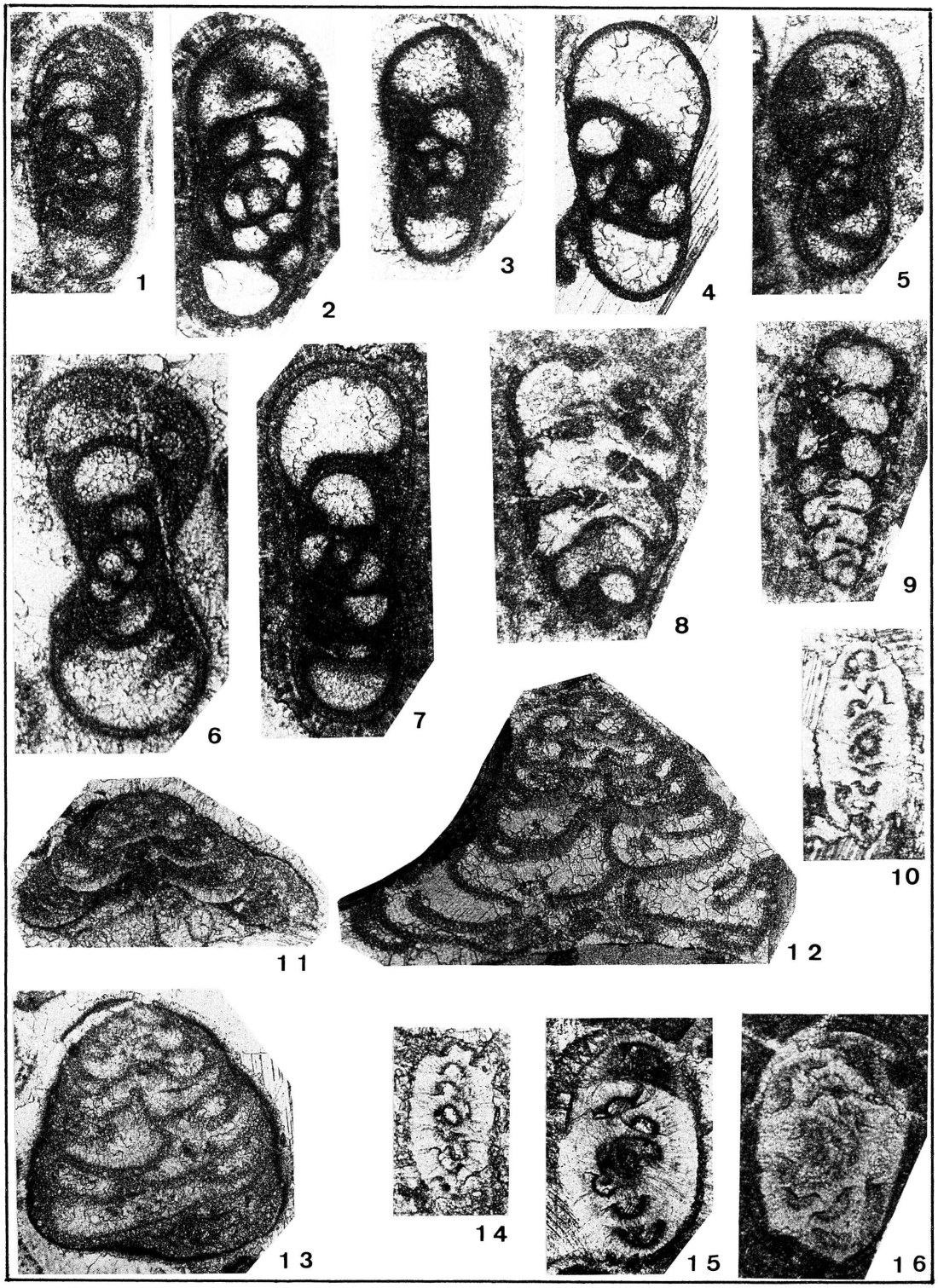
According to the present study, the distribution of foraminifers and the laminae of surrounding limestones show that the stratigraphic position of "the reddish tuffaceous shale" is regarded as an intercalated bed in the limestone of the uppermost *Endothyra* n. sp. A Zone.

In an area shown by 30 m south by 300m west from Loc. MH227, not only limestone but also other rock exposures are not found at all on the surface. This suggests that noncarbonate rocks may be distributed in subsurface of the area. HAIKAWA and OTA (1978) also suggested the possibility of distribution of the tuffaceous rocks in this unknown area.

The origin of "the reddish tuffaceous shale" has been still unknown because of its highly weathering. The bryozoans and brachiopods found from this shale are only moulds at all, but well preserved in detail. It seems that the fine tuffaceous sediments in the gentle water were inhabited by such abundant organisms above stated.

HARIYA and OHSHIMA (1963) examined the reddish tuffaceous rocks and stated that they were laminated, mainly composed of fine sand (42.3%), and were well sorted. They suggested that the reddish tuffaceous rock was probably andesite or andesitic tuff in origin as a little amount of quartz were discriminated. The writer also confirmed the presence of quartz in this shale by the X-ray diffraction method.

However, the presence of quartz in this shale requires further studies on the volcanic-activity during the early stages of deposition of the Akiyoshi Limestone Group. Because the volcanic rocks of the basal part of the Akiyoshi Limestone



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Group are olivine basaltic in this area and also in the northeastern area of the Akiyoshi Limestone Plateau (YANAGIDA *et al.*, 1971).

(3) *Mediocris mediocris* Zone

The base of the *Mediocris mediocris* Zone is defined by the first appearance of *M. mediocris*. In the eastern part of the studied area, this zonal species is found in the tuffaceous limestone which directly overlies on "the reddish tuffaceous shale". This tuffaceous limestone is reddish in color, and composed of the bioclasts of crinoids, bryozoans and rarely corals. OTA (1968) established the *Zaphrentoides* sp. Zone based on these corals from this tuffaceous limestone.

In the western part of this area, on the other hand, the lowest part of this zone includes few tuffaceous fragments and is continuous to the underlying upper part of the *Endothyra* n. sp. A Zone.

The tuffaceous matters in the eastern part of this zone, markedly and upward decrease the content, in particular. In the middle part of this zone, the tuffaceous matters are sometimes found as nucleus of some ooliths in thin sections, and they completely disappear in the upper part of this zone. The rapid decrease of the tuffaceous matters of this zone is in remarkable contrast with gradually decreasing character of those in the *Endothyra* n. sp. A Zone. These evidences suggest that the volcanic activity of the Akiyoshi district was completely closed during deposition of the *Mediocris mediocris* Zone.

Except for the basal part, the middle and upper parts of this zone are composed of mainly oolitic limestone, often containing bioclasts of brachiopods and corals. YANAGIDA (1979) reported the densely crowded occurrence of *Gigantoproductus* spp. from a coquinoid limestone at his Loc. OK203 (= Loc. MH66 auct.). The coquinoid limestones bearing brachiopods are widely distributed in the middle part of this zone; *e.g.*, at Locs. MH45 and MF74 and others along

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Explanation of Plate 7

***Endothyra* n. sp. A Zone:**

Fig. 1. *Endothyra* n. sp. A, axial section, holotype, Loc. MH205.
Fig. 2. *Endothyra* sp. B, axial section, Loc. OB46.
Fig. 3. *Endothyra* ex gr. *similis*, axial section, Loc. OB24.
Fig. 4. *Endothyra* sp. C, axial section, Loc. OB141.
Fig. 5. *Endothyra* sp. D, axial section, Loc. MH216.
Fig. 6. *Planoendothyra* cf. *sigma*, axial section, Loc. OB131.
Fig. 7. *Planoendothyra* sp. A, axial section, Loc. OB141.
Fig. 8. *Palaeotextularia* sp. A, Loc. OB108, x50.
Fig. 9. *Palaeotextularia* sp. B, Loc. MF135, x50.
Fig. 10. *Paraarchaediscus* sp., axial section, Loc. OB5.
Fig. 11. *Tetrataxis* sp. A, Loc. OB112, x50.
Fig. 12. *Tetrataxis* sp. C, Loc. OB143, x50.
Fig. 13. *Tetrataxis* sp. B, Loc. OB131.
Fig. 14. *Archaediscus* ex gr. karreri, axial section, Loc. OB8.
Fig. 15. *Archaediscus* sp. B, axial section, Loc. OB7.
Fig. 16. *Neoarchaediscus* sp. B, axial section, Loc. MF24.
(All figures x100, unless indicated otherwise)

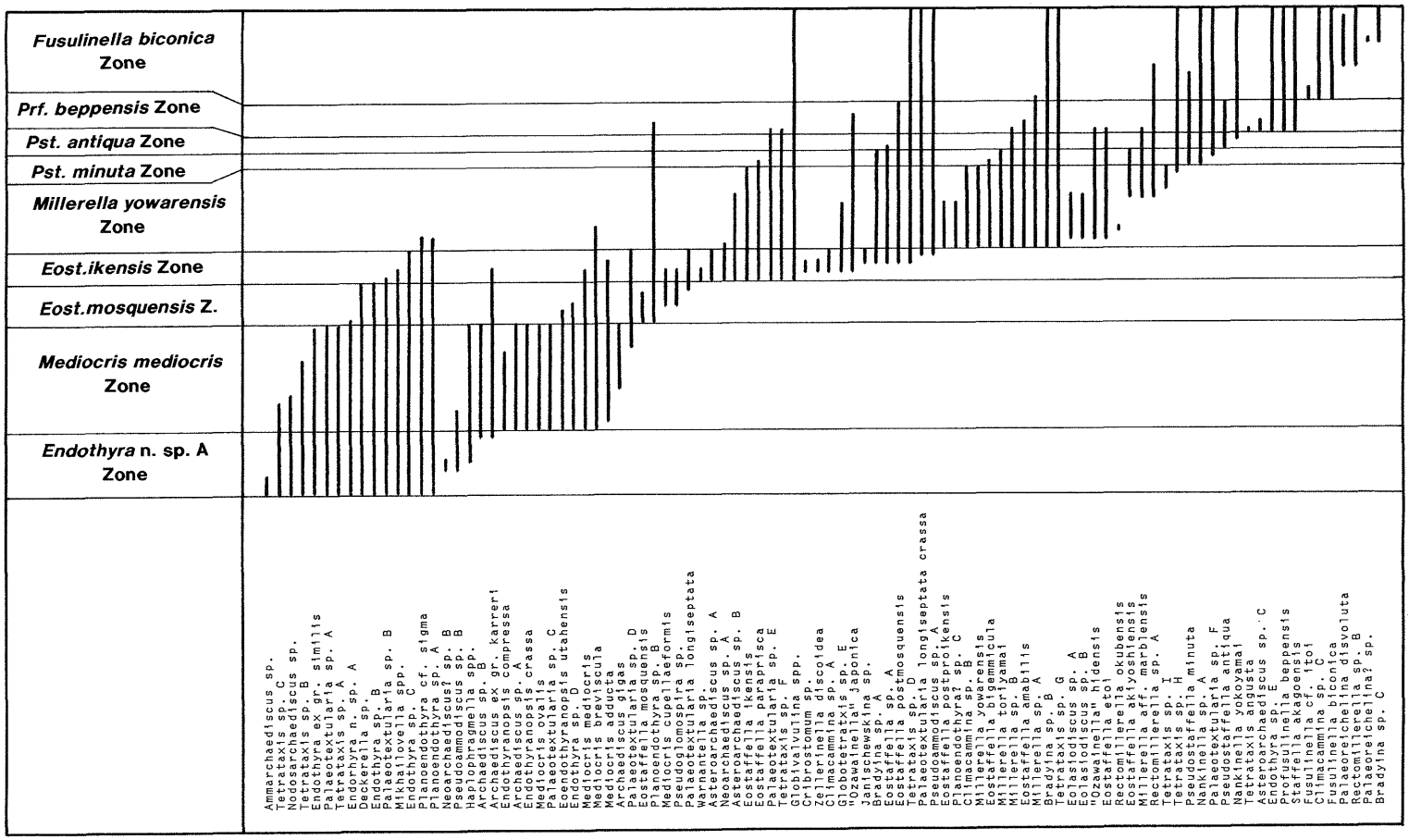


Fig. 6. Stratigraphic distribution of foraminifers in the Okubo area.

the road from Hirabara to Okubo.

Most of foraminiferal species successively occur from the underlying *Endothyra* n. sp. A Zone. Following species newly appear at the base of this zone; *Mediocris mediocris, M. breviscula, M. ovalis, Endothyranopsis compressa, E. crassa,* and *Eoendothyranopsis utahensis.* Several species of *Archaediscus* suddenly flourish in this zone, although some of them have already occurred in the upper part of the underlying zone. The foraminiferal fauna are scattered in oolitic limestone of the middle and upper parts of this zone. Moreover, heterocorals, such as *Hexaphyllia* sp. and *Radishiphyllia* sp., also occur in the nearly equivalent levels (Loc. MK651 to Loc. MK685).

Closely-packed ooliths are found in the oolitic limestones, and their intergranular spaces are only visible as light-colored lines between deformed ooliths. In the oolitic limestones, strongly sheared parts and calcite veins, which trend along the valley, are found in many localities along the road from Hirabara to Okubo. This suggests the presence of some faults or a folding along the valley. But there is not a remarkable gap in the distribution of foraminifers.

(4) *Eostaffella mosquensis* Zone

This zone is only characterized by the appearances of *Eostaffella mosquensis,* and *Planoendothyra* sp. B.

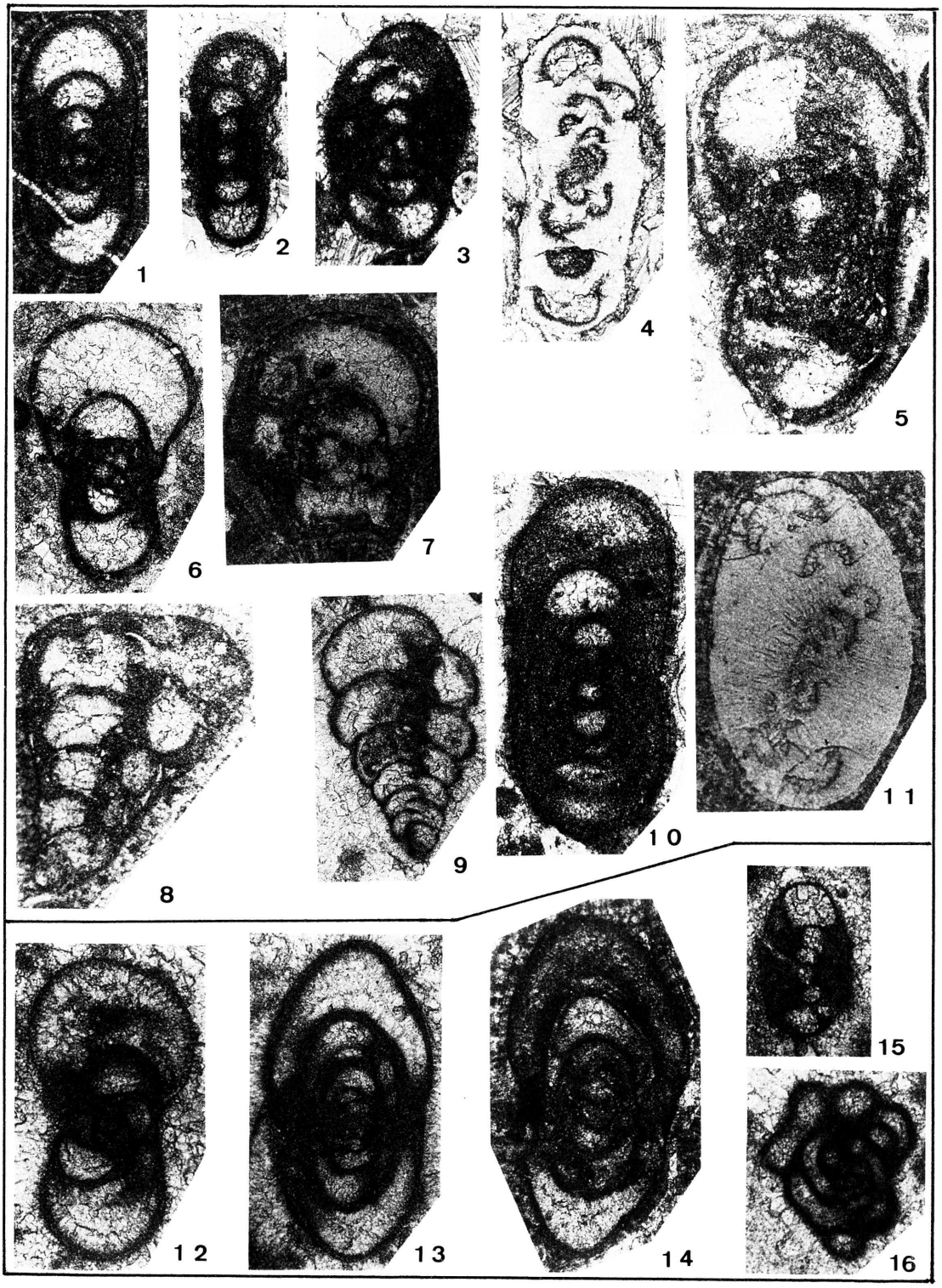
The foraminiferal assemblage of this zone is rather poor. Almost all the compositions of the *Mediocris mediocris* Zone disappear near the base of this zone. Some of them, however, such as *Mediocris cupellaeformis, Pseudoglomospira* sp., and *Palaeotextularia longiseptata,* reappear in the next zone. These suggest that some disappearances at the lower part of this zone were caused by an appearance of unfortunate depositional environment for foraminifers.

The lower part of this zone is mainly composed of oolitic limestone, succeeding from the underlying zone. To the contrary, the upper part of this zone is characterized by the crinoid-bryozoan packstone, composed of fragments of crinoids and bryozoans. This crinoid-bryozoan packstone is laterally traceable continuously, but no foraminifer present in this facies. The oolitic limestones, on the other hand, are distributed in the western part of this area along the MF route. This facies of limestone is characterized by foraminifers and brachiopods. *Gigantoproductus*? sp. and *Dictyoclostus* sp., for example, occur abundantly at Loc. MF100.

(5) *Eostaffella ikensis* Zone

OTA *et al.* (1973) established the *Millerella yowarensis* Zone as the lowest fusulinacean zone of the Akiyoshi Limestone Group. This zone was defined by occurrence of species of *Millerella* and *Eostaffella.* OTA *et al.* noted that these primitive fusulinacean genera were completely absent in the underlying *Nagatophyllum satoi* Zone.

According to the detailed examination, the first appearances of these genera are not contemporaneous. The first species of *Eostaffella* appears in the *Eostaffella mosquensis* Zone as mentioned above. Moreover, the interval characterized by abundant number of *Eostaffella ikensis* and *E. paraprisca* is discovered below the appearances of representatives of OTA's *Millerella*



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yowarensis Zone, such as *Millerella yowarensis, M. toriyamai* and *Eostaffella etoi.*

Thus, this interval, which is represented by *Eostaffella ikensis* and *E. paraprisca* without association of *Millerella yowarensis, M. toriyamai* and *Eostaffella etoi,* was defined as *Eostaffella ikensis* Zone (MATSUSUE, 1986).

The foraminiferal fauna of this zone is quite distinctive from those of the underlying zones. At the base of this zone, following foraminifers appear abundantly: *Eostaffella ikensis, E. paraprisca, Zellerinella discoidea, Climacammina* sp. A, *Neoarchaediscus* sp. A, *Asteroarchaediscus* spp., *Tetrataxis* spp. and *Globivalvulina* spp. In the upper part of this zone, some newly appeared species join them: *Eostaffella postmosquensis, E.* sp. A, *Ozawainella japonica, Janischewskina* spp., and *Bradyina* sp. A.

Moreover, *Mediocris mediocris, M. cupellaeformis, E. mosquensis, Mikhailovella,* and *Archaediscus* ex gr. *karreri,* which successively occur from the underlying zones, extinct nearly at the middle part of this zone. Heterocorals, such as *Hexaphyllia* sp. and *Pentaphyllia*? sp., also occur in this zone.

(6) *Millerella yowarensis* Zone

OTA (1971) described *Millerella yowarensis, M. toriyamai* and *Eostaffella etoi* from the Uzura Quarry, and then, OTA *et al.* (1973) established the *Millerella yowarensis* Zone, which is characterized by the Uzura fauna. OTA (1977) noted that no primitive fusulinaceans such as *Millerella* and *Eostaffella* occur in the underlying zones.

In 1986 the author redefined the lower and upper limits of the *Millerella yowarensis* Zone based on the first appearances of *Millerella yowarensis* and *M. toriyamai* and first appearance of *Pseudostaffella minuta,* respectively. Because the first appearance of *Eostaffella* is earlier than that of *Millerella.*

Besides *Millerella yowarensis* and *M. toriyamai,* the base of this zone is

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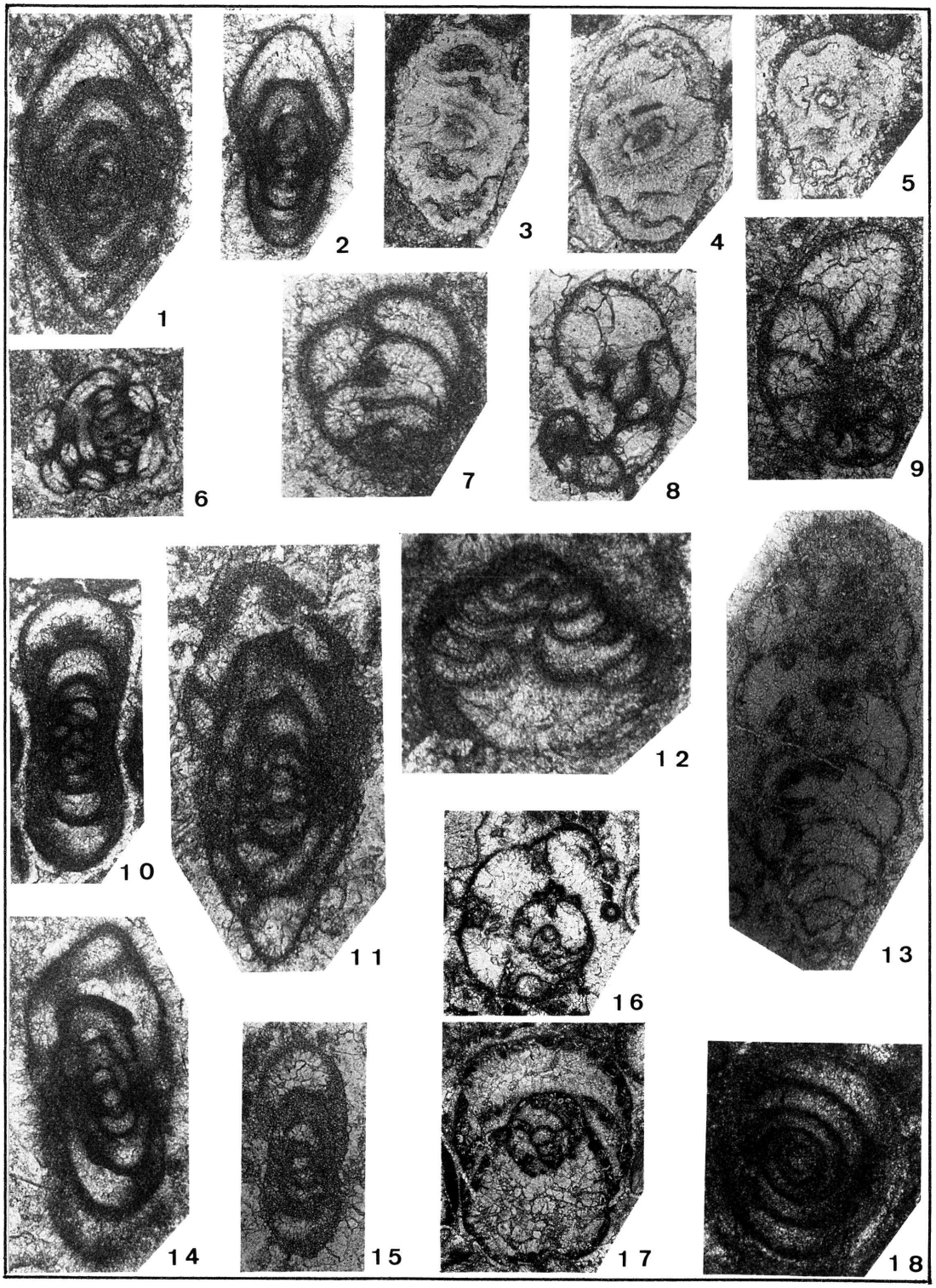
Explanation of Plate 8

Mediocris mediocris Zone:

Fig. 1. *Mediocris mediocris,* axial section, Loc. OB15.
Fig. 2. *Mediocris* breviscula, axial section, Loc. MH205.
Fig. 3. *Mediocris ovalis,* axial section, Loc. OB17.
Fig. 4. *Archaediscus* sp. A, axial section, Loc. MH207.
Fig. 5. *Eoendothyranopsis utahensis,* axial section, Loc. MH204.
Fig. 6. *Endothyranopsis compressa,* axial section, Loc. OB20, x50.
Fig. 7. *Endothyranopsis crassa,* axial section, Loc. MF82, x50.
Fig. 8. *Palaeotextularia* sp. C, Loc. OB66.
Fig. 9. *Palaeotextularia* sp. D, Loc. MF137, x50.
Fig. 10. *Mediocris adducta,* axial section, Loc. OB15.
Fig. 11. *Archaediscus gigas,* axial section, Loc. MF68.

Eostaffella mosquensis Zone:

Fig. 12. *Planoendothyra* sp. B, axial section, Loc. MF319.
Figs. 13, 14. *Eostaffella mosquensis,* axial sections; 13, Loc. MF143; 14, Loc. MK32.
Fig. 15. *Mediocris cupellaeformis,* axial section, Loc. MF107.
Fig. 16. *Pseudoglomospira* sp., Loc. MF133.
(All figures x100, unless indicated otherwise)



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characterized by appearances of many species such as *Millerella* sp. A, *Millerella* sp. B, *Eostaffella bigemmicula, E. amabilis, E. postproikensis, Planoendothyra* sp. B, *Planoendothyra*? sp. C, *Bradyina* sp. C, *Tetrataxis* sp. G, *Climacammina* sp. B, and *Warnantella* sp.

Subsequently, *Eostaffella etoi, Ozawainella hidensis, Eolasiodiscus* spp. and *Rectomillerella okubensis* appear at slightly above the base of this zone. At the middle part of this zone, *Millerella* aff. *marblensis, Eostaffella akiyoshiensis* and *Rectomillerella* sp. A appear.

The lower part of this zone is also characterized by the nearly complete extinctions of forms of the pre- *Eostaffella ikensis* Zone.

The lithofacies of this zone is remarkably different from those of underlying zones. The lower part of this zone is characterized by development of reef facies. Both massive and dendroid rugose corals occur abundantly in association with well rounded intraclasts and bioclasts, suggesting an environment under the strong wave agitation. In some localities in the lower part of this zone, either articulated or disarticulated brachiopods shells are found.

Middle to upper part of this zone are characterized by gradual decrease of the strongly wave resistant organisms, and by predominance of chaetetids and stromatolites. Concurrently, the micrite matrices increase in the upper part of this zone.

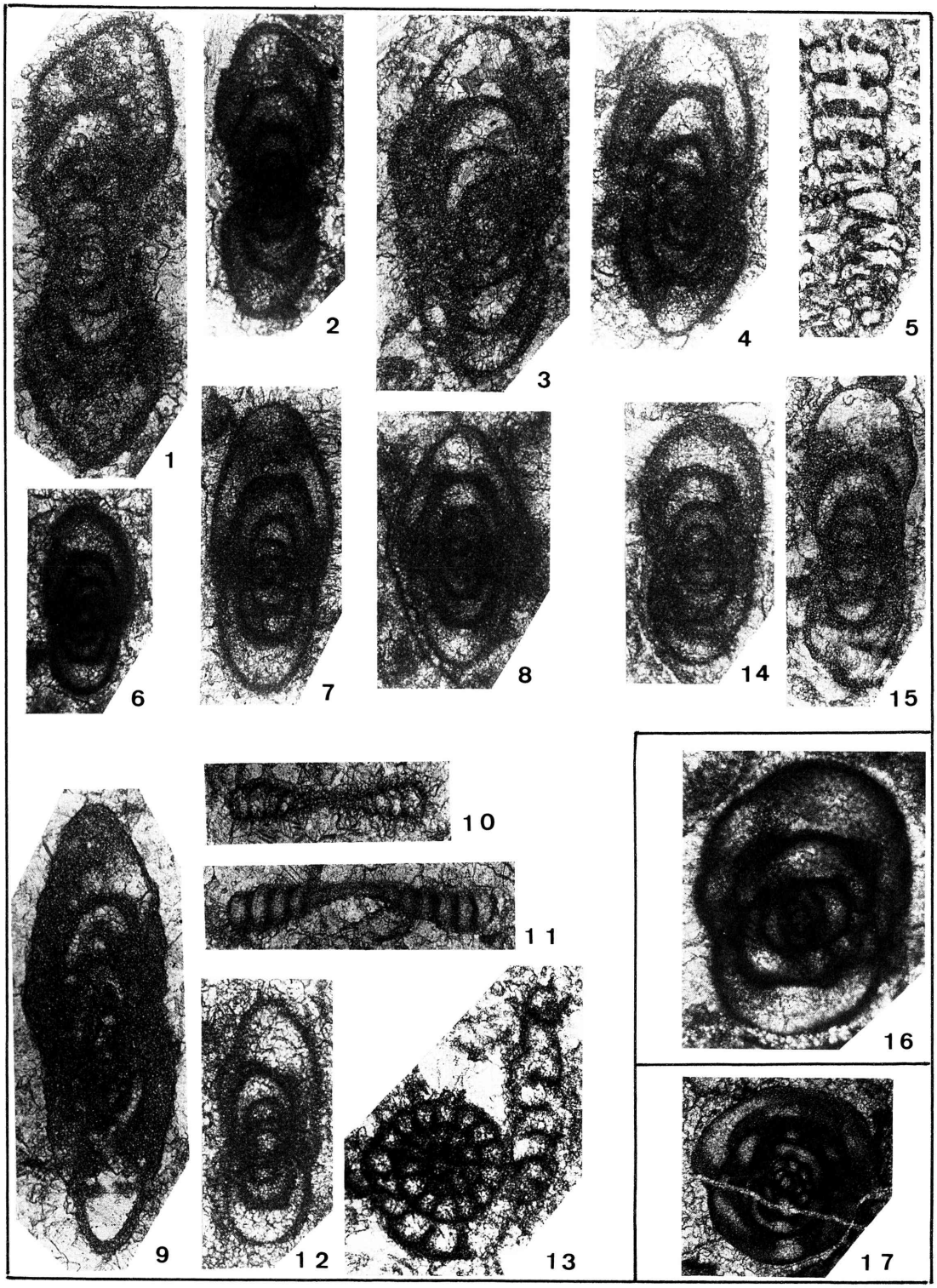
(7) *Pseudostaffella minuta* Zone

SADA (1975) described *Pseudostaffella minuta* from the sequence along the Sightseeing Road in the Hirotani area, west of Okubo. He reported that this species first occurred after appearance of *Millerella,* and before *Profusulinella,* however, the stratigraphic relation between *Peudostafella minuta* and *P. antiqua* was not clear, because the latter was not reported in the Hirotani area.

Explanation of Plate 9

***Eostaffella ikensis* Zone:**

Fig. 1. *Eostaffella ikensis,* axial section, Loc. MF125.
Fig. 2. *Eostaffella paraprisca,* axial section, Loc. MF139.
Fig. 3. *Neoarchaediscus* sp. A, slightly tangential section, Loc. MF136.
Fig. 4. *Asteroarchaediscus* sp. A, axial section, Loc. ML85.
Fig. 5. *Asteroarchaediscus* sp. B, axial section, Loc. MK274.
Fig. 6. *Warnantella* sp., Loc. MF129.
Figs. 7-9. *Globivalvulina* spp.; 7, Loc. MF150; 8, Loc. MF179; 9, Loc. MF155.
Fig. 10. *Zellerinella discoidea,* axial section, Loc. MK278.
Fig. 11. *Ozawainella japonica,* axial section, Loc. MF196.
Fig. 12. *Globotetrataxis* sp. A; Loc. MF252, x50.
Fig. 13. *Climacammina* sp. A, Loc. MF132, x50.
Fig. 14. *Eostaffella* sp. A, axial section, Loc. MF137.
Fig. 15. *Eostaffella postmosquensis,* axial section, Loc. MF217.
Fig. 16. *Janischewskina* sp., x20, sagittal section, Loc. MF137.
Fig. 17. *Bradyina* sp. A, axial section, Loc. MF141, x20.
Fig. 18. *Pseudoammodiscus* sp. A, sagittal section, Loc. MK173.
(All figures x100, unless indicated otherwise)



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As a result of the present study, it became clear to discriminate an interval characterized by only *Pseudostaffella minuta* before the appearance of *P. antiqua.* Thus, the *Pseudostaffella minuta* Zone was established as an independent zone (MATSUSUE, 1986).

This zone is characterized by the occurrence of *Pseudostaffella minuta* and *Nankinella* sp. A. Some species of *Millerella* and *Eostaffella* begin to extinct in this zone. The lithofacies of this zone is mainly composed of chaetetids and stromatolites with micritic matrix, similar to the upper part of the underlying zone.

(8) *Pseudostaffella antiqua* Zone

The lower and upper limits of this zone are defined by appearances of *Pseudostaffella antiqua* and *Profusulinella beppensis,* respectively. This zone is easily distinguished from the underlying zones by the appearance of spherical fusulinaceans. *Nankinella yokoyamai* also appears at the base of this zone. The lithofacies of this zone resembles that of the underlying zone.

(9) *Profusulinella beppensis* Zone

The base of this zone is characterized by the first occurrence of elongated fusulinids, *Profusulinella beppensis.* Besides the elongated fusulinid, foraminifers, such as *Palaeostaffella akagoensis, Tetrataxis angusta, Asteroarchaediscus* sp. C, and *Endothyra* sp. E, accompany. On the other hand, primitive fusulines common in the *Millerella yowarensis* Zone almost disappear in this zone.

YANAGIDA *et al.* (1971) divided the *Profusulinella beppensis* Zone (TORIYAMA,

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Explanation of Plate 10

***Millerella yowarensis* Zon:**

Fig. 1. *Millerella yowarensis,* axial section, Loc. MF173.
Fig. 2. *Millerella toriyamai,* axial section, Loc. MK366.
Fig. 3. *Millerella* sp. A, axial section, Loc. MF196.
Fig. 4. *Millerella* sp. B, axial section, Loc. MG55.
Fig. 5. *Climacammina* sp. B, Loc. MF196, x20.
Fig. 6. *Eostaffella amabilis,* axial section, Loc. MK376.
Fig. 7. *Eostaffella bigemmicula,* axial section, Loc. MK499.
Fig. 8. *Eostaffella postproikensis,* axial section, Loc. ML113.
Fig. 9. *Ozawainella hidensis,* axial section, Loc. MF179.
Fig. 10. *Eolasiodiscus* sp. A, slightly tangential section, Loc. MF183.
Fig. 11. *Eolasiodiscus* sp. B, axial section, Loc. MF217.
Fig. 12. *Eostaffella etoi,* axial section, Loc. MK472.
Fig. 13. *Rectomillerella okubensis,* sagittal section, Loc. MF194.
Fig. 14. *Eostaffella akiyoshiensis,* axial section, Loc. MK211.
Fig. 15. *Millerella* aff. *marblensis,* axial section, Loc. MF306.

***Pseudostaffella minuta* Zone:**

Fig. 16. *Pseudostaffella minuta,* axial section, Loc. MK480.

***Pseudostaffella antiqua* Zone:**

Fig. 17. *Pseudostaffella antiqua,* axial section, Loc. MF321, x50.
(All figures x100, unless indicated otherwise)

1957; OTA, 1968) into the lower *Profusulinella beppensis* (s. s.) Zone and the upper *Akiyoshiella ozawai* Zone in the Shishide-dai area near the northeastern margin of the plateau. In this study, the interval characterized by *Akiyoshiella ozawai* is not recognized between the *Profusulinella beppensis* and *Fusulinella biconica* Zones. *Akiyoshiella* cf. *ozawai* appears only in the overlying *Fusulinella biconica* Zone.

This seems to suggest the presence of a local hiatus in this area. But no lithological evidence of such hiatus has been found both in the field and thin sections. The extension of boundary between *Fusulinella biconica* and *Profusulinella beppensis* Zones seems to be conformable to general trends of limestones in this area.

Accordingly, the upper part of the *Profusulinella beppensis* Zone is concluded to be comparable to the *Akiyoshiella ozawai* Zone of the Shishide-dai area.

(10) *Fusulinella biconica* Zone

This is the uppermost zone of the Akiyoshi Limestone Group in the surveyed area. The base of this zone is characterized by the appearance of *Fusulinella biconica* and *Fusulinella* cf. *itoi.* Besides fusulines, *Bradyina* sp. C and *Climacammina* sp. C also appear in this zone.

The lithofacies of this zone are mainly composed of micritic facies, comparing with underlying zones. This suggests that a quiet environment like lagoon prevailed in this area.

V. Correlation

A. Comparison with previous studies of the Akiyoshi Limestone Group

a. Foraminiferal fauna of the *Millerella* Zone *sensu lato*

The *Millerella* Zone (*s. l.*) means the strata which are characterized by occurrence of such primitive fusulinaceans as the genera *Eostaffella, Millerella,* and *Pseudostaffella,* and corresponds to the interval from the *Eostaffella ikensis* to *Pseudostaffella antiqua* Zones of this study.

TORIYAMA (1957) first reported occurrence of *Millerella* from the Uzura Quarry and the Sight-Seeing Road in the Hirotani area.

OTA (1971) described *Millerella yowarensis, M. toriyamai,* and *Eostaffella etoi* from the Uzura Quarry. On the other hand, SADA (1975) described many fusulinaceans from the Sight-Seeing Road in the Hirotani area. However, YANAGIDA *et al.* (1977) pointed out that no common foraminiferal species was found from both areas. Moreover, they regarded the *Millerella* Zone in the Hirotani area as the *Pseudostaffella antiqua* Zone, because*Pseudostaffella antiqua* occurs from the lower part of the *Millerella* Zone in that area.

Some discussions on the problems mentioned above will be given as follows, based on the new data of this study. *Millerella yowarensis, M. toriyamai,* and *Eostaffella etoi,* described from the Uzura Limestone by OTA (1971), always occur in association with each other throughout the *Millerella yowarensis* Zone (s. s.) in the Okubo area except for the lowest part. In some localities of the lower part of this zone, a peculiar brachiopod genus *Weiningia* occurs in crowd. The same brachiopod is also observed in the Uzura Limestone (YANAGIDA and

MATSUSUE, 1991) and in the Ryugoho area accompanied with *Millerella yowarensis*. Therefore, the Uzura Limestone corresponds to the lower part of the *Millerella yowarensis* Zone of this study.

According to the range chart by SADA (1975), the lower part of the *Millerella* Zone in the Hirotani area (loc. OLY1-OLY5) is characterized by *Millerella marblensis* and *Ozawainella japonica,* and the upper part is characterized by *Eostaffella akiyoshiensis* and *E. bigemmicula* (OLY6-OLY20). *Pseudostaffella minuta* appears at loc. OLY11 in the upper part of the *Millerella* Zone. Both species *Millerella* ex gr. *marblensis* and *Eostaffella akiyoshiensis* appear in the middle part of the *Millerella yowarensis* Zone in the Okubo area. Therefore, the limestones disposed between the localities OLY1 and OLY10 are correlated to the *Millerella yowarensis* Zone, and the interval ranging from the OLY11 to OLY20 is correlated to the *Pseudostaffella minuta* and *Pseudostaffella antiqua* Zones in the Okubo area.

b. Comparison with OKIMURA's zonation

OKIMURA (1963, 1966) discriminated six foraminiferal biozones and six subzones in the southern margin of the Akiyoshi Limestone Plateau in which the area of this study is included. His zonation is as follows, in descending order:

Profusulinella beppensis Zone
Pseudostaffella antiqua Zone
Millerella sp. A Zone
    Eostaffella ikensis Subzone
    Millerella sp. A Subzone
Mediocris mediocris Zone
    Upper Subzone
    Lower Subzone
Endostaffella delicata Zone
    Endothyra sumiyae Subzone
    Endothyra similis Subzone
Endothyra sp. A Zone

This zonation is the first study of the Lower Carboniferous foraminiferal biostratigraphy in Japan. Since then, this zonation has been regarded as the standard zonation of the Lower Carboniferous in Japan.

OKIMURA described a part of the foraminiferal fauna from the Akiyoshi Limestone Group. But most of the fauna have been neither described nor figured. Therefore, the detailed comparison of the foraminiferal zonation between OKIMURA and the author is difficult. However, the distribution of each biozone of two studies can be compared respectively by the locality maps of them.

The *Endothyra* sp. A Zone of OKIMURA composes the lowest part of the Akiyoshi Limestone Group in this area, and is based on foraminifers from the limestone lenses in the pyroclastic rocks. This zone is comparable with the Endothyra Zone of this study by their distributions and lithology.

OKIMURA established the *Endostaffella delicata* Zone above the *Endothyra* sp. A Zone without any description and figure of *Endostaffella delicata.* In this study, *Endostaffella delicata* Rozovskaya has not been found from the surveyed area. *Endothyra* n.sp. A *and Endothyra* sp. B, however, are slightly similar to the

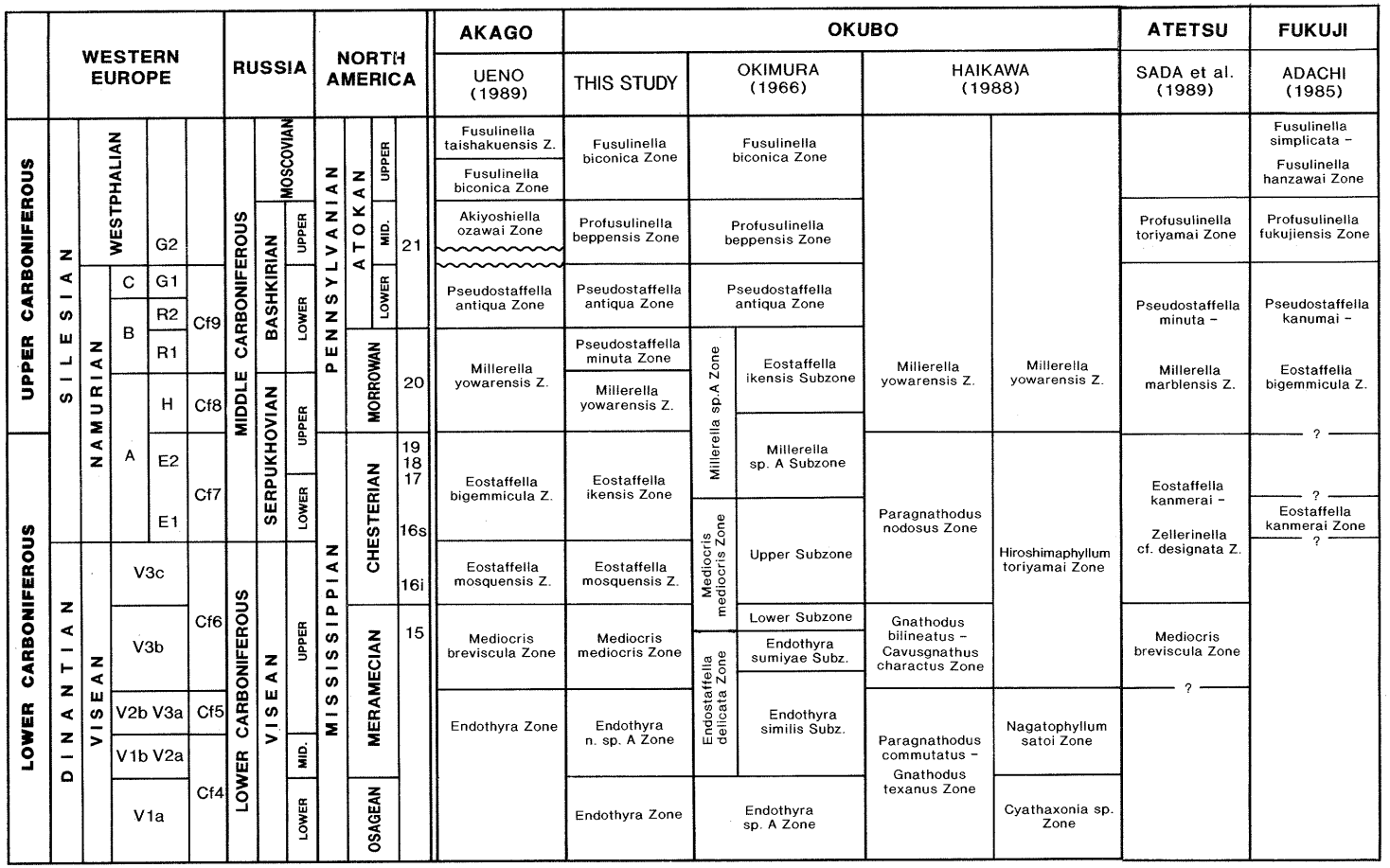

Fig. 7. Correlation chart of biozones in the lower part of the Akiyoshi Limestone Group.

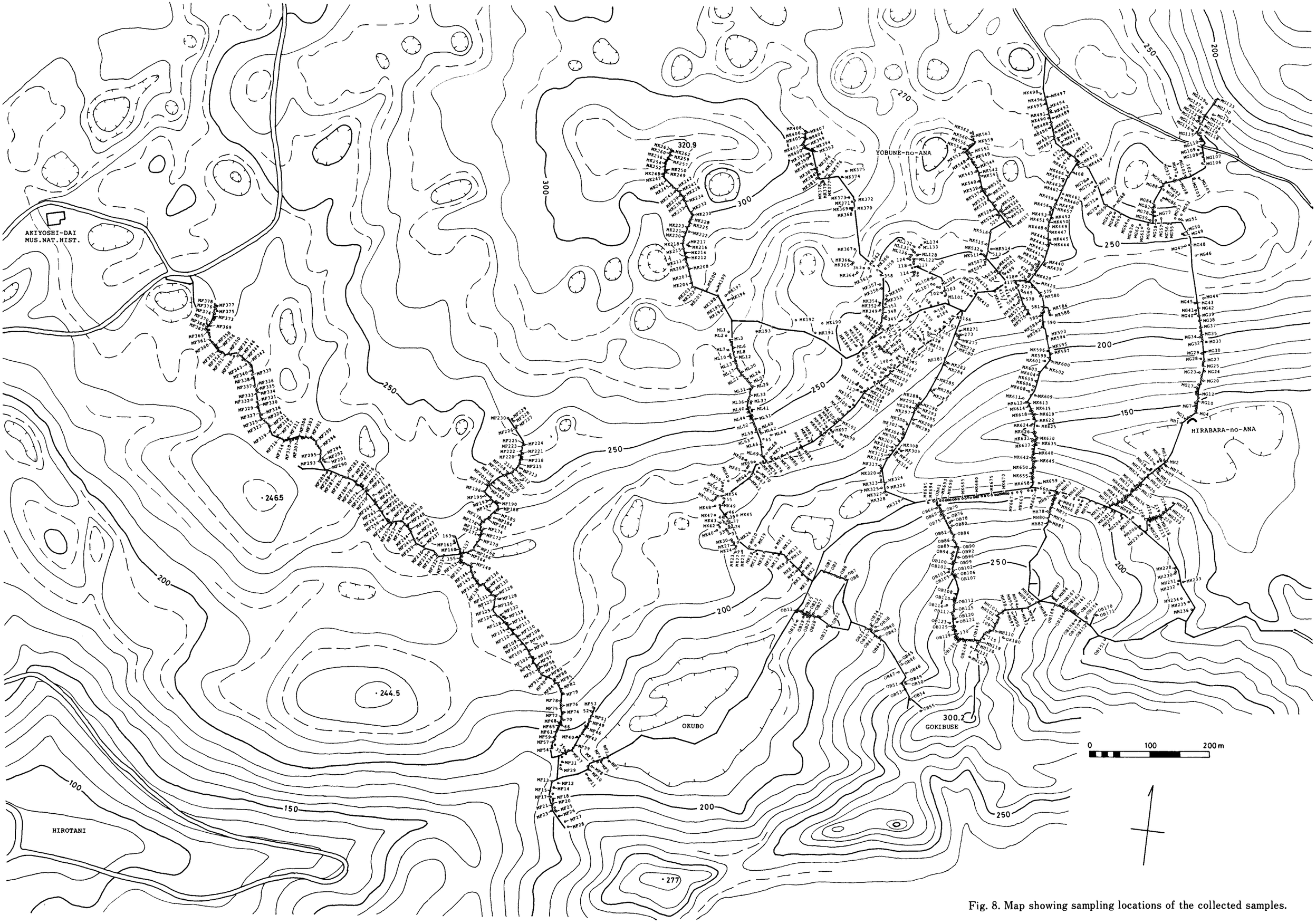

Fig. 8. Map showing sampling locations of the collected samples.

genus *Endostaffella*. These species were figured as *Endostaffella* sp. A and *E.* sp. B, respectively, in the previous paper (MATSUSUE, 1986), but they are emended, belonging to the genus *Endothyra* rather than Endostaffella for having the skew coiling.

The base of the *Endothyra similis* Subzone (= the lower part of the *Endostaffella delicata* Zone of OKIMURA) is characterized by appearances of many taxa such as *Endothyra similis, Palaeotextularia, Mikhailovella, Tetrataxis,* and archediscids. These foraminifers also appear at the base of the *Endothyra* n. sp. A Zone of this study.

The "reddish tuffaceous shale" which was first reported by HASEGAWA (1963), is intercalated at a horizon just under the *Mediocris mediocris* Zone of this study. This shale is situated between Loc. AK8 and AK9 of OKIMURA (1966, p.38). Therefore, the base of the *Mediocris mediocris* Zone of this study is correlated to the middle part of the *Endothyra similis* Subzone (Loc. AK9) of OKIMURA. OKIMURA also established the *Mediocris mediocris* Zone, but the genus *Mediocris* already appears in the underlying *Endostaffella delicata* Zone.

OKIMURA (1966, p.25) reported the primitive fusulinaceans in the Upper Subzone of the *Mediocris mediocris* Zone. According to his locality map, the Upper Subzone extends over the area of the *Eostaffella ikensis* Zone and the lower part of the *Millerella yowarensis* Zone of this study. Moreover, the Lower Subzone of the *Mediocris mediocris* Zone of OKIMURA is composed of oolitic limestones. Therefore, the Lower Subzone of his *Mediocris mediocris* Zone is correlated to the upper part of the *Mediocris mediocris* and *Eostaffella mosquensis* Zones of this study.

The *Millerella* sp. A Zone of OKIMURA is characterized by occurrence of the *Millerella* sp. A, *Eostaffella ikensis, Globivalvulina, Bradyina,* and *Climacammina.* These foraminifers are representatives of the *Eostaffella ikensis* and *Millerella yowarensis* Zones of this study. Owing to the slightly low density of sampling, it was impossible to distinguish the interval correlated to the *Eostaffella ikensis* Zone of this study.

OKIMURA divided the *Millerella* sp. A Zone into the lower, the *Millerella* sp. A Subzone, and the upper, the *Eostaffella ikensis* Subzone. Lithofacies of the lower and upper subzones are characterized by fine clastic limestones and algal limestones, respectively. According to lithofacies, the *Millerella* sp. A and the *Eostaffella ikensis* Subzones of OKIMURA are correlated to the *Eostaffella ikensis* and*Millerella yowarensis* Zones of this study.

The *Pseudostaffella antiqua* Zone of OKIMURA is characterized by occurrence of *P. antiqua* and *P. minor.* The latter is very similar to *P. minuta* Sada which represents the *Pseudostaffella minuta* Zone, and continues to the *Pseudostaffella antiqua* Zone of this study. Although the relation of first appearances between *P. minor* and *P. antiqua* is not clear, the *Pseudostaffella minuta* Zone of this study is correlated to the upper part of OKIMURA's *Eostaffella ikensis* Subzone.

c. Comparison with the coral and conodont biostratigraphy in the Okubo area

HAIKAWA (1986, 1988) studied the Okubo area, and established three coral zones and three conodont zones in the pre-*Millerella yowarensis* Zone as follows

in descending order.

Coral zones:

Millerella yowarensis Zone
Hiroshimaphyllum toriyamai Zone
Nagatophyllum satoi Zone
Cyathaxonia sp. Zone

Conodont zones:

Millerella yowarensis Zone
Paragnathodus nodosus Zone
Gnathodus bilineatus-Cavusgnathus charactus Zone
Paragnathodus commutatus-Gnathodus texanus Zone

The coral and conodont zones can be precisely correlated to the present foraminiferal zones based on the topographical distributions of each zone. The base of the *Endothyra* n. sp. A Zone is correlated to that of the *Nagatophyllum satoi* Zone. The base of the *Mediocris mediocris* Zone is equivalent to that of the *Gnathodus bilineatus-Cavusgnathus charactus* and *Hiroshimaphyllum toriyamai* Zones, respectively. The base of the *Eostaffella mosquensis* Zone is correlated to that of the *Paragnathodus nodosus* Zone.

d. Comparison with foraminiferal zonation in the northeast-ern part of the Akiyoshi Limestone Plateau

Recently two contributions for foraminiferal biostratigraphy of the lower part of the Akiyoshi Limestone Group were published.

(1) Shishide-dai area

The Shishide-dai area near the northern margin of the Akiyoshi Limestone Plateau is one of the important fields where the lower part of the Akiyoshi Limestone Group is widely exposed. The Akiyoshi Limestone Group in this area is composed of the olivine basaltic tuffs and tuff breccias of about 150m thick near the lowest part and the thick limestones on the preceding volcaniclastic rocks. YANAGIDA *et al.* (1971) discriminated the following 10 fossil zones based on fusulinaceans, corals and brachiopods, in descending order:

Pseudofusulina vulgaris Zone
Triticites simplex Zone
Beedeina akiyoshiensis Zone
Fusulinella biconica Zone
Akiyoshiella ozawai Zone
Profusulinella beppensis Zone
Pseudostaffella antiqua Zone
Millerella yowarensis Zone
Clisiophyllum awa atetsuense Zone
Delepinea sinuata Zone

Of them, the lowest two zones, the *Delepinea sinuata* and *Clisiophyllum awa atetsuense* Zones, are regarded to be equivalent to the *Zaphrentoides* sp. and *Nagatophyllum satoi* Zones, respectively, though these corals in the Okubo area have not been known in the Shishide-dai area (OTA *et al.*, 1973; OTA, 1977).

In 1981, SASHIDA described some foraminifers from the Shishide-dai area (SASHIDA, 1981). He stratigraphically divided the foraminifers into two

assemblages and referred them to the Lower and Upper Units, respectively. The Lower Unit is characterized by *Eostaffella* aff. *ikensis, Mediocris mediocris, Climacammina,* and *Endothyranopsis,* and the Upper one by *Millerella yowarensis, Eostaffella etoi, E. bigemmicula, E. postmosquensis, Globivalvulina,* and *Monotaxinoides.* These faunal assemblages first proved the interval represented by *Eostaffella* before the appearance of *Millerella* in the Akiyoshi Limestone Group.

He correlated the Lower and Upper Units to the upper part of the *Clisiophyllum awa atetsuense* Zone and the lower part of the *Millerella yowarensis* Zone of YANAGIDA *et al.* (1971), respectively. According to components of the assemblages, the Lower and Upper Units are correlated to the *Eostaffella ikensis* Zone and the lower part of the *Millerella yowarensis* Zone of the Okubo area, respectively.

SUGIYAMA (1989) subdivided the lower part of the Akiyoshi Limestone Group in the Shishide-dai area based on heterocorals and foraminifers. He discriminated six biozones from the CL1 to CL6 Zones in ascending order. He correlated the CL1 Zone to the *Zaphrentoides* sp. Zone (= the *Delepinea sinuata* Zone), the zones from CL2 to CL4 to the *Nagatophyllum satoi* Zone (=the *Clisiophyllum awa atetsuense* Zone), and the base of the CL6 Zone to that of the *Millerella yowarensis* Zone of OTA (1977).

However, the precise correlation of zonations between the Shishide-dai and the Okubo areas is difficult. Because neither the detailed stratigraphic ranges of foraminifer species nor figures of them have not been shown by SUGIYAMA.

In the Okubo area, hetrocorals are observed in the middle part of the *Mediocris mediocris* Zone and in the *Eostaffella ikensis* Zone. Among them, *Radiciphyllia* is restricted in the *M. mediocris* Zone. According to SUGIYAMA (1989), heterocorals ranges from the CL1 to CL6 Zones in the Shishide-dai area. Of these zones, *Radiciphyllia* occurs only in the CL3 Zone. The CL3 Zone is also represented by *Mediocris mediocris, M. breviscula, Endothyranopsis,* and *Archaediscus* cf. *karreri.* Therefore, the CL3 Zone may be correlated to the middle part of the *Mediocris mediocris* Zone of the Okubo area.

(2) Akago area

UENO (1989) established foraminiferal zones in the Akago area, northeastern margin of the Akiyoshi Limestone Plateau. He divided the lower part of the Akiyoshi Limestone Group into 15 biozones as follows in descending order:

Pseudofusulina ex gr. *vulgaris* Zone
Alpinoschwagerina? fusiformis Zone
Triticites "*simplex*" Zone
Quasifusulinoides toriyamai Zone
Protriticites sp. Zone
Beedeina akiyoshiensis Zone
Fusulinella taishakuensis Zone
Fusulinella biconica Zone
Akiyoshiella ozawai Zone
Pseudostaffella antiqua Zone
Millerella yowarensis Zone
Eostaffella bigemmicula Zone

Eostaffella mosquensis Zone
Mediocris breviscula Zone
Endothyra Zone

According to the range chart, the stratigraphical distribution of foraminifers in the Akago-Managatake area is very similar to that of the Okubo area.

The *Endothyra* Zone is composed of calcareous tuff in the lower part and tuffaceous limestone in the upper part. It is the transitional layer from underlying pyroclastic rocks to overlying limestones. YANAGIDA (1968) described *Delepinea sinuata* and *D. sayamensis* from the calcareous tuff of the lower part of the zone. Foraminiferal fauna is very poor in the lower part of the zone. But many taxa appear in the tuffaceous limestone of the upper part: such as *Endothyra* spp., *Endothyranopsis* ex gr. *crassa,* Eoendothyranopsis utahensis, Archaediscus spp., *Neoarchaediscus* sp. and others.

The overlying *Mediocris mediocris* Zone is composed of mainly oolitic limestones, and is characterized by the first appearances of many taxa (such as *Mediocris mediocris, M. breviscula,* and *Palaeotextularia* ex gr. *longiseptata*), and an outburst of archaediscids. Although the specific name of the leading fossil is different, the *Mediocris breviscula* Zone of the Akago and *Mediocris mediocris* Zone of Okubo areas are quite similar to each other in their faunal characters. Besides *Mediocris,* some foraminifers representing the *M. breviscula* Zone, however, appear in the underlying *Endothyra* Zone in the Akago area. This may be indicative of the appearance of *Mediocris* in the Akago area was later than the Okubo area.

The *Eostaffella mosquensis* Zone of the Akago area can be correlated to the same zone of the Okubo area on the basis of the first appearance of the genus *Eostaffella.*

The base of the *Eostaffella bigemmicula* Zone of the Akago area is characterized by appearances of many species of *Eostaffella, Climacammina,* and *Eolasiodiscus.* Moreover, *Ozawainella* cf. *japonica, O. hidensis,* and *Janischewskina* appear in the upper part of this zone. On the other hand, this zone is also characterized by declines of *Endothyra, Mediocris mediocris,* and archaediscids. In the Okubo area, *Eostaffella bigemmicula, E. amabilis, E. etoi, Ozawainella hidensis,* and *Eolasiodiscus* appear in the lower part of the overlying *Millerella yowarensis* Zone.

Although the stratigraphic ranges of each of foraminifers are slightly different between two areas, the *Eostaffella bigemmicula* Zone may be correlated to the *Eostaffella ikensis* Zone of the Okubo area. The transitional character of foraminiferal assemblages through these intervals is very common with each other.

The base of the *Millerella yowarensis* Zone in the Akago area is correlated to that in the Okubo area by the first appearance of the genus *Millerella.*

In the Okubo area, the *Pseudostaffella minuta* Zone is discriminated between the *Millerella yowarensis* Zone and the *Pseudostaffella antiqua* Zone. The upper part of the *Millerella yowarensis* Zone of the Akago area probably includes the strata correlated to the *Pseudostaffella minuta* Zone, although *Pseudostaffella minuta* has not been found in the Akago area.

The exact correlations on the post- *Millerella yowarensis* Zones between the

Okubo and Akago areas are uncertain. OTA (1977) summarized the Akiyoshi Limestone Group, and discriminated the following fusulinacean zones in the lower Upper Carboniferous in ascending order: the *Millerella yowarensis* Zone, the *Pseudostaffella antiqua* Zone, the *Profusulinella beppensis* Zone, the *Akiyoshiella ozawai* Zone, the *Fusulinella biconica* Zone. The last zone was subdivided into three parts by representative species: the lower part by *Fusulinella simplicata,* the middle part by *F. biconica,* and the upper part by *F. itoi.*

In the Okubo area, the *Akiyoshiella ozawai* Zone has not been discernible, and *Akiyoshiella* cf. *ozawai* appears at the base of *Fusulinella biconica* Zone.

In the Akago area, on the other hand, *Profusulinella beppensis* appears at the base of the *Akiyoshiella ozawai* Zone, and *Fusulinella* cf. *itoi* occurs in the lower part of the *Fusulinella biconica* Zone.

UENO established the *Fusulinella taishakuensis* Zone above the *Fusulinella biconica* Zone. However, *Fusulinella taishakuensis* Sada (in SADA and YOKOYAMA, 1970) is very similar to *Fusulinella itoi* OZAWA, 1925, as already pointed out by SADA (in SADA and YOKOYAMA, 1970). GINKEL (1987, p.232) considered that these species such as *Fusulinella itoi, F. taishakuensis, F. subpulchra, F. eopulchra,* and *F. nuxoidalis* belong to a single species group of *Fusulinella* ex gr. *itoi* et *subpulchra.*

These problems mentioned above may be related to the areal hiatus in the Akiyoshi Limestone Group. The latter is fundamentally closely connected with development of the Akiyoshi Organic Reef Complex in an oceanic environment.

B. Correlation in Japan

a. Comparison with the Ichinotani Formation

IGO (1957) reported the fusulinacean fauna from the Ichinotani Formation, Fukuji, Gifu Prefecture, Central Japan. Recently, the detailed biostratigraphy of foraminifers, including both smaller foraminifers and the primitive fusulinaceans, has been shown by ADACHI (1980 and 1985), IGO and ADACHI (1981) and IGO, ADACHI and IGO (1984). According to those studies, the Lower Member of the Ichinotani Formation is divided into four units.

The unit 1, the lowest part, is characterized by occurrence of *Eostaffella komatui, E. kanmerai, Zellerinella, Mediocris, Bradyina, Globivalvulina, Asteroarchaediscus, and Neoarchaediscus.* Among them, *E. komatui, E. kanmerai, Zellerinella* and *Mediocris* are restricted within the unit 1.

In the Akiyoshi Limestone Group, *Eostaffella mosquensis, Zellerinella,* and *Mediocris* disappear in the *Eostaffella ikensis* Zone. *Eostaffella mosquensis* is very similar to *E. kanmerai.* On the other hand, *Bradyina, Globivalvulina,* and *Asteroarchaediscus* appear in the *Eostaffella ikensis* Zone. Therefore, the unit 1 of the Ichinotani Formation is correlated to the *Eostaffella ikensis* Zone of Akiyoshi.

ADACHI (1985) presumed a disconformity between the unit 1 and the unit 2 by abrupt change of faunal elements between them. The unit 2 is characterized by *Ozawainella hidensis, O. japonica, Eostaffella etoi, Pseudostaffella kanumai,* and *Profusulinella* sp. Of them, *Pseudostaffella kanumai,* which may be identifiable to *P. antiqua,* appears at the base of the unit, and *Profusulinella* sp. occurs in the upper part of the same unit. On the other hand, in Akiyoshi, *Ozawainella hidensis,*

O. japonica, and *E. etoi* well associate from the lower part of the *Millerella yowarensis* Zone up to the *Profusulinella beppensis* Zone. Accordingly, the unit 2 of the Ichinotani may be correlated to the *Pseudostaffella antiqua* Zone and the lower part of the *Profusulinella beppensis* Zone of Akiyoshi.

The overlying units 3 and 4 are characterized by *Millerella toriyamai, Eostaffella bigemmicula, Nankinella yokoyamai,* and *Profusulinella fukujiensis.* In the Akiyoshi Limestone Group, both *M. toriyamai* and *E. bigemmicula* are extinct at a horizon just under the *Profusulinella beppensis* Zone. However, appearances of *Nankinella yokoyamai* and *Profusulinella fukujiensis* indicate that the units 3 and 4 are correlated as a whole to the *Profusulinella beppensis* Zone, especially to the upper part of it.

b. Comparison with the Atetsu Limestone

The Atetsu Limestone exposed in the Okayama Prefecture, Southwest Japan is named the Mitsudo Group. The Mitsudo Group is composed of two formations; the lower, the Nagoe Formation and the upper, the Kodani Formation. SADA *et al.* (1989) discriminated the foraminiferal zones in the Atetsu Limestone, as follows in descending order:

Kodani Formation
Profusulinella toriyamai Zone
Pseudostaffella minuta–Millerella marblensis Zone
Nagoe Formation
Eostaffella kanmerai–Zellerinella cf. *designata* Zone
Mediocris breviscula Zone

The foraminiferal zonation of the Atetsu Limestone is similar to that of the Akiyoshi Limestone Group. The *Mediocris breviscula* Zone is correlated to the *Mediocris mediocris* Zone of Akiyoshi. The *Eostaffella kanmerai-Zellerinella* cf. *designata* Zone may be correlated to the interval between the *Eostaffella mosquensis* Zone and the lower part of the *Millerella yowarensis* Zone in Akiyoshi. Because *Eostaffella kanmerai* is very close to *E. mosquensis,* and *Millerella* ex gr. *marblensis* is absent in the Atetsu Limestone. The *Pseudostaffella minuta-Millerella marblensis* Zone is correlated to the interval between the upper part of the *Millerella yowarensis* Zone and the *Pseudostaffella antiqua* Zone.

C. The Mid-Carboniferous boundary in the Akiyoshi Limestone Group

The mid-Carboniferous boundary problem has been debated for long time (RAMSBOTTOM *et al.*, 1982; LANE and MANGER, 1985a, b). A final recommendation on the mid-Carboniferous boundary was presented by the adhoc mid-Carboniferous boundary Committee in 1983, as follows;

1) The boundary shall correspond approximately to the change from the *Eumorphoceras* to *Homoceras* ammonoid zones.

2) It is recommended that the stratigraphic level that marks the appearance of the conodont *Declinognathodus noduliferus* should be used in selecting a mid-Carboniferous boundary stratotype.

3) The evolutionary appearances of other species be utilized as auxiliaries

to define or approximate the boundary. These auxiliary species include the following ones;

Globivalvulina sp. D of BRENCKLE, 1973
(= *Globivalvulina moderata* REITLINGER)
Millerella pressa THOMPSON
Millerella marblensis THOMPSON
Adetognathus lautus (GUNNELL)
Rhachistognathus primus DUNN
Rhachistognathus minutus (HIGGINS and BOUCKAERT)

These recommendations were approved by the Subcommission on Carboniferous Stratigraphy meeting at 10th Carboniferous Congress in Madrid, 1983. Since that time, a new working group has continued to examined the proposed stratotypes (SKIPP *et al.*, 1989).

Figure 6 shows that the foraminifers of the lower part of the Akiyoshi Limestone Group can be divided into two groups on their stratigraphic distributions. The first group is composed of species stratigraphically restricted in occurrence below the *Millerella yowarensis* Zone. The second one, on the other hand, consists of species which appear in the *Eostaffella ikensis* Zone or overlying zones. The faunal change at this level is recognized not only within genera, such as *Tetrataxis* and *Palaeotextularia,* but also within families, such as Archaediscidae and Palaeotextulariidae.

In particular, the *Eostaffella ikensis* Zone is characterized by the extinction of the preceding first group and the appearance of the second one. OKIMURA (1967) formerly suggested a great faunal change under the *Millerella* sp. A Zone, and presumed a hiatus at the level. But the faunal change at this level seems to be gradually progressive throughout the *Eostaffella ikensis* Zone.

The first group consists of genera such as *Endothyranopsis, Eoendothyranopsis, Viseidiscus, Paraarchaediscus, Archaediscus, Mikhailovella, Haplophragmella, Pseudoglomospira* and *Deckerella,* and other long ranged genera, such as *Endothyra, Planoendothyra, Tetrataxis, Mediocris, Palaeotextularia,* and *Pseudoammodiscus.* These genera are representatives of the middle to upper Visean of Western Europe and Russia, and of the Meramecian to lower Chesterian of North America.

As regard to the second group, some differences are recognized in the foraminiferal assemblages between the *Eostaffella ikensis* and *Millerella yowarensis* Zones.

The assemblage of the *Eostaffella ikensis* Zone is closely related to the upper Visean (Cf6 Zone) of Western Europe, the upper Visean of Russia, and the lower Chesterian (Zone 16) of North America. However, *Eostaffella mosquensis* is also reported from the upper Visean and the Cf6 Zone of Belgium (ROZOVSKAYA, 1963; CONIL *et al.*, 1979).

On the other hand, among the fauna of *Millerella yowarensis* Zone, *M. yowarensis, M. toriyamai,* and *Eostaffella etoi* are the representatives from the Uzura Quarry limestone. According to distributions of those forms in the Okubo area, the Uzura Quarry limestone is correlated with lower part of the *Millerella yowarensis* Zone.

Many faunas have been described from the quarry; corals (Yamagiwa and

OTA, 1963), brachiopods (YANAGIDA, 1962, 1965), bryozoans (SAKAGAMI, 1964), conodonts (IGO and KOIKE, 1965; IGO and IGO, 1979), gastropods (NISHIDA, 1963), and fusulines (OTA, 1971).

There is a great deal of controversy about the age of the Uzura fauna. YANAGIDA (1962, 1965) considered that the age of the brachiopod fauna from the Uzura Quarry was the late to latest Visean. OTA (1971) suggested the faunal similarities of the primitive fusulinaceans between the Uzura fauna and the North American Upper Chesterian fauna.

IGO and KOIKE (1965), on the other hand, examined the conodont fauna from the Uzura Quarry and compared the age of the fauna with the earliest Pennsylvanian or the latest Mississippian. They remarked that there was strong possibility of the earliest Pennsylvanian. IGO and IGO (1979), based on the further conodont materials from the quarry, concluded that the conodont fauna was equivalent to those of the Lower Pennsylvanian Morrowan Series of North America or the Upper Namurian of Western Europe.

In the lowest part of the *Millerella yowarensis* Zone, most of species of *Millerella* have subangular peripheries and rather deep umbilici. These features are similar to those of *Millerella rossica* which was reported from the upper Visean of Russia and Western Europe (ROZOVSKAYA, 1963; CONIL and LYS, 1964).

On the other hand, North American micropaleontologists have considered that *Millerella marblensis* which has rounded peripheries first appears at the base of Pennsylvanian (ARMSTRONG and MAMET, 1977). In the Akiyoshi Limestone Group, *Millerella* aff. *marblensis* with rounded peripheries that appears at the middle part of the *Millerella yowarensis* Zone.

In 1986, the author, therefore, placed the Mississippian-Pennsylvanian boundary at the middle part of the *Millerella yowarensis* Zone, and correlated the lower part of this zone with the lower Namurian, the lower Serpukhovian and the upper Chesterian.

However, the upper part of the Chesterian is characterized by *Eosigmoilina* (SKIPP *et al.*, 1985). On the other hand, the Lower Serpukhovian of the Russian Platform is represented by foraminifers of globular forms, such as *Pseudoendothyra globosa* and *Eostaffellina decurta* (VDOVENKO *et al.*, 1990). But these representatives of the uppermost of the Lower Carboniferous have not been found in the Akiyoshi Limestone Group. This may suggest the presence of a hiatus between the *Eostaffella ikensis* and the *Millerella yowarensis* Zones. However, there is no evidence of unconformity in the lithology and the distribution of biozones.

Recently, HAIKAWA (1988) found two conodont species, *Declinognathodus noduliferus* and *Paragnathodus commutatus,* from the Uzura Quarry, although the detailed stratigraphic relation of them was not discussed. The first appearance of former species is the initial indicator of the mid-Carboniferous boundary, and the latter is at most known from the lower Namurian or the upper Chesterian. The occurrence of *D. noduliferus* supports IGO and IGO (1979) who compared the conodont fauna from the Uzura Quarry to the Morrowan. Moreover, the co-occurrence of *Paragnathodus commutatus* suggests the mid-Carboniferous boundary which is traceable somewhere in the quarry.

SKIPP *et al.* (1985) figured *Millerella pressa* from the Lowest Pennsylvanian of Idaho, U. S. A. The Idaho specimens have rather deep umbilici and subangular peripheries, so that they are very similar to *Millerella yowarensis* from Akiyoshi.

As mentioned above, the age of the lower part of the *Millerella yowarensis* Zone should be correlated with the Pennsylvanian. However, there remained some questions about another auxiliary foraminifer, *Globivalvulina moderata.*

MAMET (in ARMSTRONG and MAMET, 1974) distinguished the genus *Biseriella* from the genus *Globivalvulina* by its wall structure. ARMSTRONG and MAMET (1977) noted that three-layered *Globivalvulina* appears on the base of Morrowan, but single-layered *Biseriella* first appears in the upper Mississippian. The first appearance of *Globivalvulina moderata* is also understood to recognize the beginning of the Pennsylvanian (LANE and MANGER, 1985a, b).

In the Akiyoshi Limestone Group, whereas, both three- and single-layered *Globivalvulina* occur in the *Eostaffella ikensis* Zone together with other Lower Carboniferous foraminifers. It is indeed that some *Globivalvulina* have light color layer within wall, although it is only partially recognizable in general. The author has some doubts about the availability of the genus *Biseriella.* The difference of wall structure of globivaluvulins may be referable to degrees of the preservation.

In 1992, the author considered that the mid-Carboniferous boundary lies at the base of the *Millerella yowarensis* Zone, according to the complete extinction of the Lower Carboniferous foraminifers and the appearance of the Upper Carboniferous forms (MATSUSUE, 1992). This correlation is conformable to the occurrence of *Declinognathodus noduliferus* from limestones of the Uzura Quarry in the lower part of the *Millerella yowarensis* Zone. However, further studies are required to establish the detailed conodont zonation across the mid-Carboniferous boundary in the Akiyoshi Limestone Group.

D. International correlation

Lower Carboniferous foraminifers have been studied in Russia, North America, and Western Europe since 1940s. A huge number of genera and species were proposed. There are two foraminiferal biostratigraphic schemes.

The first is known by the name of the MAMET Foraminiferal Zones (MAMET and SKIPP, 1970, 1971; MAMET, 1974). The MAMET Foraminiferal Zones have been used generally in North America. However, BAXTER and BRENCKLE (1982) claimed the data by MAMET that his foraminiferal zones did not accurately reflect the stratigraphic succession. The author has not had an opportunity to examine all data for foraminiferal zonation in North America. So, the author will discuss about the correlation between MAMET's foraminiferal zones and those of this study.

In Western Europe, CONIL (in CONIL *et al.,* 1976; CONIL *et al.,* 1979) established the Carboniferous foraminiferal zones (ranging from Cf1 to Cf9) in the Dinantian and the lower Silesian. PAPROTH *et al.* (1983) reviewed the bio- and lithostratigraphic
subdivisions of the Dinantian and the Silesian in Belgium.

(1) *Endothyra* Zone

The foraminifers from the *Endothyra* Zone are poorly preserved for the reason of recrystallization. Although there is no characteristics, this zone may be correlated to the Lower Visean, according to the relation to the overlying zone.

(2) *Endothyra* n. sp. A Zone

Endothyra n. sp. A is very similar to *Planoendothyra* sp. 1 ex gr. *barzassiensis* (LEBEDEVA, 1954) from the Cf4β Zone (V1b) figured by GROESSENS *et al.* (1979, pl.10, figs. 222-224). This species was originally described as *Endothyra barzassiensis* by LEBEDEVA (1954) from the Perfishkin Limestone of Kuznetsk, and was translated to *Endostaffella* by MAMET (in ARMSTRONG and MAMET, 1977, p.64).

In Western Europe, the Cf4β Zone is characterized by appearance of the genus *Viseidiscus* (=*Ammarchaediscus*), and the Cf4δ Zone (V2a) is characterized by *Paraarchaediscus* (= *Nodosarchaediscus*).

Accordingly, the base of the *Endothyra* n. sp. A Zone of the Okubo area is correlated to the upper part of the Cf4 Zone of Western Europe, and the Middle Visean of Russia.

(3) *Mediocris mediocris* Zone

The majority of the species of *Mediocris* occurs throughout the Visean. *Endothyranopsis compressa* and *Eoendothyranopsis utahensis* are known from the MFZ13 and MFZ14 Zone of the North America, respectively. *Endothyranopsis crassa* appears in the Cf6γc Zone (V3bγ) of Western Europe, however, it is also known in the Tulsky Horizon of the Russian Platform.

On the other hand, *Archaediscus* ex gr. *gigas* appears in the middle part of this zone. This group occurs in the Alexinsky Horizon of the Russian Platform, and in the Cf6γ Zone of Western Europe.

Accordingly, the *Mediocris mediocris* Zone is correlated to the Alexinsky Horizon of Russia, the lower Cf6 Zone (V3b) of Western Europe, and the Upper Meramecian of North America.

(4) *Eostaffella mosquensis* Zone

A few representatives are recognizable in this zone. *Eostaffella mosquensis* is reported from the Okskian Horizon and the Cf6δ Zone (V3c). Therefore, this zone may be correlated to the uppermost Visean of Russia and Western Europe.

(5) *Eostaffella ikensis* Zone

This zone is characterized by appearances of many taxa, such as *Eostaffella ikensis, Eostaffella paraprisca, Asteroarchaediscus, Bradyina, Climacammina* and *Zellerinella discoidea.* They represent the Okskian Horizon (the upper Visean) of Russia, the Cf6γ-δ Zone (V3c) of Western Europe, and the MFZ16 Zone (the lower Chesterian) of North America.

Eostaffella postmosquensis Kireeva was described from the Moscovian. But the older record of it is from the Protvinsky Horizon (lower Upper Serpukhovian), according to Grozdilova and LEBEDEVA (1975).

Janischewskina representing the upper part of this zone ranges up to the Upper Serpukhovian (EINOR, 1979). On the other hand, AIZENVERG *et al.*, (1963) reported the occurrence from the C_{1e}^{v} Zone of the Donetz (= the Tulsky Horizon of the Russian Platform). Besides Russia, the range of *Janischewskina* is restricted within V3 of Western Europe (CONIL *et al.*, 1979), but it ranges from the MFZ14 to 16 Zones of North America (MAMET, 1974).

As mentioned above, the foraminifers of this zone are related to that of the Upper Visean and the lower Chesterian.

Although there are some uncertainties, the *Eostaffella ikensis* Zone is highly probable to be correlated to the Lower Serpukhovian, the Upper Chesterian (from the MFZ17 to 19 Zones), and the Cf7 Zone (the lower Namurian A).

(6) *Millerella yowarensis* Zone

As mentioned above, the base of this zone is equivalent to the Mid-Carboniferous boundary. Therefore, this zone is correlated to the Morrowan of North America, the upper Upper Serpukhovian of Russia, and the upper Namurian of Western Europe.

(7) *Pseudostaffella minuta* and *Pseudostaffella antiqua* Zones

The genus *Pseudostaffella* appears at the upper Lower Bashkirian (the Severokeltmensky Horizon) of the Russian Platform, and at the base of the Cf9 Zone (Namurian B and C) in Western Europe.

In North America, formerly, the boundary between the Morrowan and the Atokan Series was defined by the appearance of the genus *Profusulinella* (DOUGLASS, 1977; ROSS, 1979). Recently, some questions about the boundary in the type Atokan have been shown by Sutherland and MANGER (1983). GROVES (1986, 1988) emphasized that the base of the Atokan was well defined by *Pseudostaffella,* and was correlated to the Akavasky Horizon of the Ural Mountains.

Pseudostaffella antiqua is regarded as the most primitive species of the genus, and first appears in the Severokeltmensky Horizon (the upper Lower Bashkirian) of the Russian Platform. However, *Pseudostaffella minuta* is more primitive form than *Pseudostaffella antiqua,* and is very close to *Pseudostaffella minor.* In the Akiyoshi Limestone Group, *Pseudostaffella minuta* first occurs just below the appearance of *Pseudostaffella antiqua,* although *Pseudostaffella minor* and *P. antiqua* appear at the same level in Russia.

Accordingly, the *Pseudostaffella minuta* Zone is correlated to the lowest Bashkirian and uppermost Morrowan of North America. The *Pseudostaffella antiqua* Zone is correlated to the upper Lower Bashkirian and the lower Atokan.

(8) *Profusulinella beppensis* and *Fusulinella biconica* Zones

The genera *Profusulinella* and *Fusulinella* appear in the Upper Bashkirian and the middle Atokan, and in the Moscovian and the Upper Atokan, respectively. Therefore, the *Profusulinella beppensis* Zone is correlated to the Upper Bashkirian and the middle Atokan, and the *Fusulinella biconica* Zone is correlated to the Moscovian and the Upper Atokan.

VI. Conclusion

According to the detailed field survey and microscopic analysis of thin sections, the lower part of the Akiyoshi Limestone Group exposed in the Okubo area is divided into 10 foraminifer zones, as follows in descending order:

Fusulinella biconica Zone
Profusulinella beppensis Zone
Pseudostaffella antiqua Zone
Pseudostaffella minuta Zone
Millerella yowarensis Zone
Eostaffella ikensis Zone
Eostaffella mosquensis Zone
Mediocris mediocris Zone
Endothyra n. sp. A Zone
Endothyra Zone

These foraminifer biozones are distributed from south to north in ascending order with general trend of WSW-ENE direction, ranging from the Early Visean to the Moscovian in age.

According to the distribution of biozones and measurements of laminae, a homoclinal structure of limestones dipping south, and completely reversed order are recognized in this area This homoclinal and reversed structure is essentially same in both north and south sides of a big valley of E-W trend, bisecting the surveyed area. As far as the Okubo area is concerned the normal order of limestone sequence has been considered for long time. The relation of the geologic structure between this area and the northern adjacent areas reported as the normal order of limestone sequence remains indistinct. This is one of the most important problems to make clear.

The foraminiferal biostratigraphy established in the Okubo area is essentially equal to that established by UENO (1989) in the Akago area, northeastern part of the Akiyoshi Limestone Plateau. Moreover, foraminiferal biozones can be precisely correlated to coral and conodont zones established in the Okubo area (HAIKAWA, 1986 and 1988). Therefore, the biostratigraphy of the pre-*Millerella yowarensis* Zone of the Akiyoshi Limestone Group has been completely established.

In 1986, the author placed the Mississippian-Pennsylvanian boundary in the middle part of the *Millerella yowarensis* Zone, and correlated the lower part of the zone with the lower Namurian, the lower Serpukhovian, and the upper Chesterian.

Foraminifers of the lower part of the Akiyoshi Limestone Group can be divided into two groups based on their stratigraphic distributions. Most species of the first group are stratigraphically restricted below the *Millerella yowarensis* Zone, and the species of the second one, on the other hand, appear in the *Eostaffella ikensis* Zone or the overlying zones. The faunal change at this level is recognized not only within families, such as Archaediscidae and Palaeotextulariidae, but also within genera such as *Tetrataxis* and *Palaeotextularia*.

In conclusion, it is considered that the mid-Carboniferous boundary lies at

the base of the *Millerella yowarensis* Zone, according to the complete extinction of the Lower Carboniferous foraminifers and the appearance of the Upper Carboniferous forms. This correlation is conformable to the occurrence of *Declinognathodus noduliferus,* the initial indicator of the mid-Carboniferous boundary, from the Uzura Quarry situated in the lower part of the *Millerella yowarensis* Zone. However, further studies are required to establish the detailed and successive conodont zonation across the mid-Carboniferous boundary in the Akiyoshi Limestone Group.

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