DISTRIBUTION OF THE UPPER PERMIAN FUSULINIDS WITH RELATION TO LIMESTONE LITHOFACIES IN THE SOUTHERN KITAKAMI MOUNTAINS, N. E. JAPAN

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I. Introduction

Although much have been done as to the taxonomic and biostratigraphic studies on fusulinids in recent few decades, palaeoecological studies have just begun in recent years by few workers (Ross, 1965, 1969, 1971; OHTA, 1968).

Ross advocated in his works that thick fusiform species of *Triticites* mainly lived in shallow water, while *Triticites* with elongate shells in slightly deep water under wave base. He also considered that most of fusulinids lived in water less than 4 to 5 meters (Ross, 1971). The framework of the upper Palaeozoic reef complex was reconstructed by OHTA (1968) in the Akiyoshi limestone, Japan. He mentioned that fusulinids have best adapted to marginal lagoon to beach environment.

The writer lately has extended his research to palaeoecological study on fusulinids in the so-called upper Permian Kanokurayama limestone in the Setamai district, Southern Kitakami Mountains, since he came to notice and was much interested in the close relationships between areal distribution of fusulinids and lithological nature of limestones containing them.

This paper intends to clarify the relationship between habitat of each fusulinid species and depositional environment of the Kanokurayama limestone in the upper Permian sedimentary basin in the Kitakami Mountains.

II. Brief note on the stratigraphy of the type Kanokura series, middle to upper Permian in age

For the sake of general comprehension of the geological setting of the Kanokurayama limestone, the stratigraphy of the type Kanokura series is here briefly summarized.

Geological map around Mt. Kanokurayama is shown in Fig. 1. The Kanokura series shows generally a transgressive phase that begins with basal conglomerate. The series is mainly occupied by well sorted arkose sandstone with less amount of calcareous slate in the lower section, while it consists of well bedded limestone, the so-called Kanokurayama limestone, and non bedded slate in the upper section (Figs. 1—4). The lower part chiefly consisting of sandstone is called the Kattisawa stage, and the upper half composed of limestone and black slate the Iwaizaki stage (ONUKI, 1937; MINATO, 1944; MINATO *et al.*, 1954; CHOI, 1973).

Fossils are profuse throughout the series. Brachiopods, bryozoans and fusulinids are especially abundant in some horizons of calcareous sandstone of the Kattisawa stage. But in the Kanokurayama limestone, brachiopods are quite rare. To the contrary, crinoids, fusulinids, bryozoans, and calcareous algae are plentiful, although corals are only sparsely found. Fusulinids and corals are discovered in association in some horizons of the Kanokurayama limestone. They are indicated in Figs. 2 & 3.

Thickness of the Kanokurayama limestone

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Fig. 1. Geological map around Mt. Kanokurayama and Kotsubosawa.

Fig. 2. Columnar sections of the Kanokurayama limestone in east-west direction showing stratigraphical occurrence of fossils.

Fig. 3. Columnar sections of the Kanokurayama and the Kotsubosawa in north-south direction, showing stratigraphical occurrence of fossils.

Fig. 4. A schematic profile of the Kanokura bank in east-west direction. Small dotted areas indicate sandy facies; thickly dotted areas, conglomerate facies; open areas (no pattern), slate facies.

attains at least 180 meters as a whole in the thickest part.

One may refer the writer's previous paper (CHOI, 1973) on biostratigraphy and fusulinid taxonomy in the present district. The lower to middle Kattisawa stage was named the *Monodiexodina matsubaishi* zone, and the upper the *Colania kotsuboensis* zone by him, and the Iwaizaki stage was called the *Lepidolina multiseptata* zone.

The Setamai-Yahagi district extending linearly from north to south is now interpreted to have been the areas where marine banks or mounds have developed in some places, such as the Kanokura, Imo and Iwaizaki areas, in middle to upper Permian, since comparatively thin sandstone and limestone with a number of fossils dwelled in shallow facies have deposited there. But on the contrary, the districts adjacent east and west to the Setamai-Yahagi district presumably have been under slightly deep marine condition, because there is predominated by comparatively thick black slaty facies with thin sandstone beds showing load cast, graded bedding, and almost lacking in fossils. There the thick Usuginu-type conglomerates which are considered as channel deposits have accumulated mainly in early half of the upper Permian (Fig. 4).

The Kanokurayama limestone is considered to have deposited on such a shallow bank as the above mentioned in the Permian shelf sea, for which the writer proposes a new name, the Kanokura bank.

III. Classification of the Kanokura-yama limestone

Fossiliferous limestones are good horizon markers in the Kanokurayama limestone. A lithological study was made especially on the limestones from these fossiliferous horizons (Horizons 1—VI in Fig. 2).

The limestones are largely divided into the following three types from its lithological nature and association of fossils.

1. Micritic limestone.
2. Foraminiferal limestone.
3. Crinoid-algal limestone.

These types are shortly described as follows.

1) Micritic limestone, central facies.

The rock commonly possesses microcrystalline calcite matrix with small amount of fossils such as corals, foraminifers and fragments of algae, crinoids and bryozoans as biogenic constituents. Foraminifers and corals are relatively free from abrasion, and in some cases almost complete skeletal construction is preserved (Pl. I, figs. 1 & 2). But conversely algae and crinoids are fragmental without exception, so they may have been transported from other places. These facts suggest that this type of limestone have deposited in relatively quiet and deep water under wave base.

Micritic limestone is further divided into the following four subtypes.

Micritic limestone s. str......The rock is white to pale pink or sometimes light grey in colour, somewhat compact with less amount of crinoidal and algal fragments. The matrix is usually recrystallized, but where free from recrystallization, it is composed of micritic to microsparitic calcite, 4 to 12 microns in diameter.

Foraminiferal micritic limestone.....The rock is fundamentally the same with the above described subtype, but contains slightly larger calcite in matrix often with limonite crystals and relatively abundant foraminifers. The shells of foraminifers are weakly eroded away. This type of limestone yields such foraminifers as *Lepidolina minatoi*, *Lepidolina multiseptata gigantea*, *Pseudodoliolina gravitesta* and *Kahlerina pachytheca*.

Muddy limestone.....The rock well develops in the Kotsubosawa district, south of Kanokura-yama. It is dark grey in colour, with plentiful dark muddy fragments, and limonite crystals. The matrix is large calcite. Foraminifers are sometimes comparatively abundant. The shells of fossils are more or less eroded.

Colonial coral micritic limestone.....The rock contains colonial corals, often being muddy and dark grey in colour. Other nature is the same with micritic limestone s. str. mentioned above. Colonial corals are usually well preserved and almost free from destruction. The largest corallum that the writer has ever discovered attains as large as 1 meter in diameter. Foraminifers associated with colonial corals preserve also complete shells. Colonial corals are *Waagenophyllum* (*Waagenophyllum*) *virgalense*, *Waagenophyllum* (*W.*) *indicum*, both of which are phaceloid in form, and *Wentzelella* (*Szechuanophyllum*) *kitakamiensis* of cerioid form. Colonial corals may have lived as small knolls in calm environment, relatively deep water, under effective wave base. Since they are lying parallel to the bedding plane of limestone, they may have fallen down into gentle, slightly muddy calcareous bottom after death, and deposited gently with other organisms. As far as the writer's observation in the Kitakami Mountains goes, this kind of limestone is frequently encountered in the Carboniferous Onimaru and Nagaiwa limestones but it is rare in the lower Permian Sakamotosawa limestone.

2) Foraminiferal limestone, intermediate facies.

This type of limestone is remarkable from its abundant yield of foraminifers. They occupy over about 30% areas of the limestone surface. According to FOLK's (1959) classification the rock is named foraminiferal biomicrudite to biosparudite. Fossils are all fragmental and arranged in parallel on the bedding plane, which shows the deposition under wave influence (Pl. I, fig. 6). Biogenic constituents are cemented by recrystallized calcite which is considered to have been originally microsparite to sparite. Limonites are also found but rare.

A limestone shown in pl. I, fig. 5 shows

sparitic matrix with foraminiferal shells quite well abraded and sorted. It well agrees with a limestone illustrated by OHTA (1968) in his pl. 6, fig. 2 as foraminiferal sandy limestone. He regarded it as typical beach sand facies.

3) Crinoid-algal limestone, marginal facies.

This type of limestone occupies the main part of the Kanokurayama limestone. It is very well bedded, containing crinoidal stem joints and algae as main biogenic component with less amount of foraminifers, brachiopods, and molluscs. The matrix consists of sparite and recrystallized large pseudosparite.

The following three subtypes are discriminated in this type of limestone.

Foraminifer-crinoidal limestone.....The rock contains foraminifers and crinoidal fragments as main biogenic constituent. Algal fragments are less frequent, and bryozoans, brachiopods and molluscs are less in amount. All grains are well abraded.

Crinoidal limestone.....Fundamentally the same with the last named subtype, but possessing especially abundant crinoids. One of limestones of this subtype (Pl. II, fig. 5) is composed of crowded crinoidal stems which appear to have composed crinoid mound.

Crinoid-algal limestone s. str......Generally contains large sparite or pseudosparite in matrix, and dominantly composed of crinoidal and algal fragments with rare foraminifers, solitary and tabulate (?) coral fragments.

IV. Reconstructed sedimentary environment of the Kanokurayama limestone

On the basis of field observations (Figs. 2 & 3) and lithology of the limestones, a stratigraphical profile of the Kanokurayama limestone in east-west direction was reconstructed as

shown in Fig. 5. This figure well demonstrates the vertical and horizontal distribution of each type of limestones.

Micritic limestone distributes in the central area, being surrounded by foraminiferal limestone. Crinoid-algal limestone develops most outward, surrounding these two types of limestone.

Horizontal distribution of lithofacies around Mt. Kanokurayama is indicated in Fig. 6 for each fossiliferous horizon. As shown in the figure, all the three types of limestone have maintained the above mentioned specific distribution pattern throughout the Kanokura epoch; micritic limestone at the center, foraminiferal limestone encircling it, and crinoid-algal limestone occupying the outermost areas.

All informations concerning the limestone lithology of the Kanokurayama limestone reveal that the sedimentary environment of the limestone may be roughly comparable to those of recent atoll reefs studied by KUENEN (1950), MCKEE *et al.* (1959), FAIRBRIDGE (1950), EMERY (1948), LADD *et al.* (1950) and others. The areas occupied by micritic limestone correspond to relatively deep central lagoon, foraminiferal limestone to marginal lagoon, and crinoid-algal limestone to reef-like shoals near water surface as illustrated in Fig. 7.

However, the sedimentary environment of the limestone may have not been quite the same with those of recent coral reefs, since everywhere the Kanokurayama limestone is well bedded and any coral community considered to have composed the frameworks of coral reefs can not be found in the limestone as mentioned by MINATO (1975).

Fig. 5. A reconstructed stratigraphical profile of the Kanokurayama limestone in east-west direction showing distribution of limestone types. Numerals indicate fossil localities in a previous paper (CHOI, 1973) from where fusulinids and corals were obtained. Legend is the same with that of Fig. 6.

Fig. 6. Changes of lithofacies distribution around Mt. Kanokurayama in the Kanokura epoch.
The right side figure shows limestone lithofacies.
I: Kattisawa stage. II-VII: Iwaizaki stage. For I—VI see Figs. 2 & 3.

Fig. 7. Relative abundance of foraminifera, algae and crinoid in the restored environment of the Kanokurayama limestone.

V. Areal distribution of fusulinids in the restored palaeoenvironment of the Kanokurayama limestone

Fig. 8 illustrates the areal distribution of some upper Permian fusulinids and corals in the Kanokurayama and the Kotsubosawa areas, regardless of their horizons. After examination on the horizontal distribution of each fusulinid and coral species for each fossiliferous horizon, areal distribution in the reconstructed environment of the Kanokurayama limestone was induced as shown in Fig. 9.

From these figures, the following tendencies are recognized.

1. Fusulinids possessing elongate cylindrical shells with relatively thin wall and septula, and large proloculi are exclusively found in micritic to foraminiferal limestones which are often muddy. They appear to have best adapted to relatively quiet and somewhat deep water below effective wave base.

(1). The largest and endemic neoschwagerinid species, *Lepidolina minatoi*, and its related species, *Lepidolina kumaensis* with elongate cylindrical shells are most abundant in micritic limestone, but rare in foraminiferal limestone which contains muddy fragments in matrix.

(2) *Pseudodoliolina gravitesta*, *Pseudodoliolina kanokuraensis*, and *Pseudodoliolina elongata*, all of which are characteristic fusulinid elements of the present district also occur in micritic to foraminiferal limestones.

2. The species with fusiform to inflated fusiform shells and comparatively thick wall

and septa are widely distributed regardless of limestone lithofacies. They may have been more tolerant to environment than elongate forms such as *Lepidolina minatoi*.

Lepidolina multiseptata, *Parafusulina* sp., and *Chusenella* sp. are found throughout all of limestone lithofacies. The former two are frequently found associated with each other in crinoid-algal limestone, in which their shells are severely abraded and destroyed. They also often occur in association in arenitic limestone composing conglomerate matrix around the Setamai-Yahagi district.

To be worthy of note is that *Lepidolina multiseptata shiraiwensis* group and *Lepidolina multiseptata gigantea* group, the latter of which possesses slightly more elongate shells with thinner spirotheca and septula, and larger proloculi than the former seem to show somewhat different horizontal distribution from each other. The former is frequently found in crinoid-algal limestone, while the latter in micritic to foraminiferal limestones in association with *Lepidolina minatoi* or *Pseudodoliolina* and *Kahlerina*. It is probable that this difference has resulted from their different adaptability to the environments.

3. *Kahlerina* with subsphaerical shells occurs most abundantly in micritic to foraminiferal limestones. The same is also observable in the occurrence of *Pseudoschwagerina schellwieni*, which also possesses subsphaerical shells and is a species of the Sakamotosawa series, lower Permian. These species may have chiefly inhabited in gentle, somewhat deep environments, under wave base. OHTA (1968) also stated that *Pseudostaffella* with sphaerical shells is abundant in lagoon side of reef in association with crinoidal stem fragments.

4. *Nankinella* with minute rhomboidal shell is mostly found in muddy micritic to foraminiferal limestones. This genus appears to have best adapted to deep water and slightly muddy environments.

5. Though not found in the Kanokurayama limestone, it is interesting in ecological viewpoint that *Codonofusiella* having aberrant last volution is found in foraminiferal to arenitic limestones intercalated in slaty facies.

The just mentioned tendencies in distribu-

Fig. 8. Areal distribution of the upper Permian fossils around Mt. Kanokurayama and Kotsubosawa.

I. & I': *Lepidolina minatoi* area. II & II': *Pseudodoliolina* area. III & III': *Lepidolina multiseptata* and *Parafusulina* area. IV: Area where fossils are rare.

tion pattern are found not only in the Kanokurayama limestone but also in the limestones around the Setamai-Yahagi district, and further wide in the upper Permian terrain of Japan.

Figs. 10 and 11 show the distribution of the upper Permian limestones and fusulinids around the Setamai-Yahagi district. As demonstrated in these figures, *Lepidolina multiseptata*

commonly occurs in association with *Parafusulina* and *Chusenella* throughout the said district, but *Lepidolina kumaensis*, *Lepidolina minatoi*, *Pseudodoliolina gravitesta* and some coral species are restricted in their distribution. These tendencies seem to have been derived from the different adaptability of each species to various environments.

The distribution of the *Yabeina* and the

Fig. 9. Distribution of fusulinids and corals in the restored environment of the Kanokurayama limestone.

Lepidolina faunas in the Japanese upper Permian is illustrated in Fig. 12. The *Yabeina globosa* realm is extending as a narrow, long belt, occupying the central region. The *Lepidolina multiseptata* realm distributes distally adjacent to the *Yabeina globosa* realm, and further outward the *Lepidolina kumaensis*-*Lepidolina multiseptata* realm is present.

This concentric pattern of distribution implies the dominance of shallow, shoaly environments in the axial part of Southwest Japan during the upper Permian. It can be referred as an indirect evidence proving that *Lepidolina multiseptata* with inflated shells have had broader tolerance to environments than *Lepidolina kumaensis* with elongated cylindrical shells.

VI. Conclusion

To sum up the above the followings are concluded.

1. The Kanokurayama limestone has deposited on a bank mainly composed of sandstones previously existed on the Permian shelf under conditions roughly comparable with recent atoll reef.

Fig. 10. Distribution of the upper Permian limestones around the Setamai-Yahagi district.

2. The palaeoenvironments of the Kanokurayama limestone are inferred as follows; the central part of the Kanokura bank was a central lagoon, somewhat deep and muddy. Encircling it the marginal lagoon presented. The outermost part might have been under a reef-like shallow condition.

3. Fusulinids have most flourished in the marginal lagoon where wave agitation was not so hard, and supplied with enough light and nutrients, but they were rare in reef-like shoals and the central lagoon. This well agrees with OHTA's (1968) conclusion in the Akiyoshi limestone, Japan and JELL *et al.*'s (1965) observations in recent reef sediments of the Heron Island in the Great Barrier Reef.

Colonial corals lived at places in lagoon forming small knolls. Reef-like shoals were

Fig. 11. Distribution of some upper Permian fusulinids around the Setamai-Yahagi district.

1: *Lepidolina multiseptata*. 2: *Lepidolina minatoi* and *Lepidolina kumaensis*. 3: *Pseudodoliolina*.

mainly composed of crinoids and algae with less amount of bryozoans, foraminifers, brachiopods and molluscs.

4. Fusulinid species with elongate shells, thin wall and septa such as *Lepidolina kumaensis*, *Lepidolina minatoi* and *Pseudodoliolina* have best adapted to comparatively deep water, under wave base, and slightly muddy environments such as lagoon.

5. *Kahlerina pachythea* with subsphaerical shells and *Nankinella* with minute rhomboidal shells also lived mainly in relatively deep

Fig. 12. Realms of *Yabeina* and *Lepidolina* faunas in Japan.

□ : *Yabeina globosa* fauna
○ : *Lepidolina multiseptata* fauna
● : *Lepidolina kumaensis*-*Lepidolina multiseptata* fauna

water.

6. Species with inflated fusiform shells and comparatively thick wall such as *Lepidolina multiseptata*, *Chusenella*, and thick forms of *Parafusulina* have lived abundantly in shallow water near and on the reef-like shoals. They appear to have been more tolerant to environments than the species with elongate shells, since they occur throughout all of limestone lithofacies.

7. *Lepidolina multiseptata gigantea* mostly occurs in limestones which have deposited presumably under relatively deep, gentle conditions. But *Lepidolina multiseptata shiraiwensis* was abundant in shallow environment. The difference in skeletal construction between these two subspecies might have resulted from their different adaptability to the environment, characterized by a wider range of environmental factors such as nutrients, light, temperature, and salinity, which participated in forming their calcareous skeletons.

8. The recognized tendency in distribution pattern of fusulinids well agrees with that of *Triticites* clarified by Ross (1965, 1968, 1971).

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南部北上山地における石灰岩岩相との関連から見た上部ペルム紀紡錘虫類の分布

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(要 旨)

南部北上山地、世田米西方の叶倉山一帯に分布する上部ペルム紀の叶倉山石灰岩は、ペルム紀初期から存在した南北方向に長く伸びた海底の隆起帯上の堆の上に堆積したものと思われる。

叶倉山石灰岩は micritic limestone, foraminiferal limestone, crinoid-algal limestone の三つの型に大別される。これらの石灰岩について各時代ごとの水平的分布関係を見ると、中央部に泥質部が優勢な micritic limestone が分布し、それを取りまいて foraminiferal limestone が分布する。さらに外側は crinoid-algal limestone で占められている。石灰岩を構成する生物遺骸の摩滅の程度は外側へ向けて著るしくなっており、基質の方解石の結晶も外側へ向けて大きくなる傾向が認められる。したがって、礁性のサンゴが発見されず、また石灰岩全体に一般によく成層している事を考えれば、叶倉山石灰岩は現世の環礁とは異なるが、ややそれに近い環境下で堆積したものと推定される。すなわち、micritic limestone の分布域が礁湖中央部に、foraminiferal limestone 分布域が礁湖縁辺部に、そして crinoid-algal limestone 分布域が礁の部分に相当したものと推定される。

このように復元された環境の中での生物の分布を見ると、礁湖中央部には生物は少なく、礁湖縁辺部に有孔虫が繁栄し、海百合、石灰藻は礁性の環境に最も適応し棲んでいたものと考えられる。

次に紡錘虫の分布傾向を見れば、横に長い殻をもち殻壁のうすい紡錘虫類、すなわち *Lepidolina minatoi*, *Lepidolina kumaensis*, *Pseudodoliolina* 等、小型でレンズ形の殻をもつ *Nankinella*, そしてふくれた亜球形をなす *Kahlerina* 等は micritic limestone~foraminiferal limestone 中に多産するが、crinoid-algal limestone 中に産

することはまれである。特に neoschwagerinids では世界最大の殻をもつ *Lepidolina minatoi* は例外なく泥質な micritic limestone から産している点が注目される。さらに筆者の見限りでは、大きなふくれた亜球形の殻をもつ lower Permian の *Pseudoschwagerina schellwieni* もこれと全く同様な産状を示している。

これに対し、ふくれた紡錘形をなす *Lepidolina multiseptata*, *Chusenella*, *Parafusulina* 等は micritic limestone から crinoid-algal limestone にかけて広く分布している。このような種類は多様な環境に適応する能力があった可能性がある。ただし *Lepidolina multiseptata gigantea* は micritic-foraminiferal limestone 中に多産するのに対し、*Lepidolina multiseptata shiraiwensis* は foraminiferal-algal limestone 中に産する傾向が認められる。

以上のような紡錘虫類の分布傾向は、叶倉山石灰岩のみならず南部北上地に広く認められ、さらに日本各地の上部ペルム紀の紡錘虫地理区に見られる傾向とも合致する。またこれは太田 (1968) により秋吉台石灰岩で明らかにされた紡錘虫の古生態とも矛盾せず、Ross (1965, 1969, 1971) により研究されたアメリカテキサス州の *Triticites* に見られる生態的分布ともほぼ一致している。

地 名			
Akiyoshi	秋 吉	Onimaru	鬼 丸
Kanokurayama	叶倉山	Setamai	世田米
Kattisawa	合地沢	Usuginu	薄 衣
Kotsubosawa	小坪沢	Yahagi	矢 作
Nagaiwa	長 岩		

Explanation of plates

Plate I: All figures are 3.8 times natural size except for fig. 1.

- Fig. 1; A colonial coral obtained as a float at Ohbune, a small tributary of the Kanokurasawa. Original skeletal construction is well preserved, and corallites are almost free from abrasion. It may have lived as a small knoll under gentle marine condition. Limestone matrix was painted black. *Waagenophyllum* (*Waagenophyllum*) *virgalense*.
- Fig. 2; Colonial coral micritic limestone. Transverse section of *Waagenophyllum* (*W.*) *virgalense*. Corallites are almost completely preserved. Note the association of *Waagenophyllum* and *Lepidolina*. Northern slope of Mt. Kanokurayama. UHR 19286-2.
- Figs. 3 & 4; Micritic limestone. Limestones are slightly muddy, recrystallized with matrices composed of pseudomicrosparite. Fig. 3, Northern slope of Mt. Kanokurayama. UHR 19278-1, Fig. 4, Eastern ridge of Mt. Kanokurayama. UHR 19301-5.
- Figs. 5 & 6; Foraminiferal limestone. Fig. 5, Well abraded fusulinid shells are embedded in pseudosparite, showing the deposition of beach-like environment. Loc. Kotsubosawa. UHR 19313-11. Fig. 6, Fusulinids are depressed and deformed. Note the orientated arrangement of fusulinid shells. Loc. The middle course of the Kanokurasawa. UHR 19329-7.

Plate II: All figures are 3.8 times natural size.

- Fig. 1; Foraminiferal limestone. Abraded fusulinid shells and calcareous algae as biogenic constituents. Note the orientated arrangement of fusulinid shells. Loc. Mt. Kanokurayama. UHR 19282-36.
- Fig. 2; Crinoid-algal limestone. A section vertical to the bedding plane. Loc. The middle course of the Kattisawa. UHR 19277-1.
- Fig. 3; Foraminifer-crinoid fragments limestone. Biogenic constituents are all fragmental and severely eroded away, showing deposition under wave agitation. Matrix is composed of largely recrystallized pseudosparite. Loc. Western slope of the Kattisawa. UHR 19280.
- Figs. 4, 5 & 6; Crinoidal limestone. Fig. 4, Crinoids are all fragmental. Loc. Western slope of the Kattisawa. UHR 19800. Fig. 5, A limestone inferred to have composed crinoid mound. Loc. Kotsubosawa. UHR 19346-4. Fig. 6, Fusulinid shells are completely replaced. Foraminifers, crinoids and algae are embedded in pseudosparite. Loc. Western slope of the Kattisawa. UHR 19298.