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Collenia (algal stromatolites) from the Hida Mountainland, Central Japan*

(Studies on the Paleozoic Marine Algae of Japan-5)

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Introduction

The purpose of this paper is two-fold; 1) to report the occurrence of algal stromatolites of *Collenia*-type from Japan for the first time, and 2) to discuss the sedimentary environment of the stromatolites-bearing polymict conglomerate fringing along the southern margin of the Hida Metamorphic Complex.

The conglomeratic formation called in different stratigraphic names of too local nature occurs in the Hida Tectonic Marginal Belt and is characterized with red bed associations accompanied with volcanic sediments. The conglomerates consist of gravels of granite, graphic granite, granodiorite, aplite, granophyre, quartz porphyry, andesite, porphyrite, serpentinite, phyllites, chert, sandstone, slate, shale and limestone. They are poorly sorted in general, and contain huge boulders up to 1 m in diameter occasionally. Three divergent K-Ar radiometric ages have been obtained from some granitic cobbles in the conglomerate, for instance, at Kamihirosé, Kokufu Village, north of Takayama City, Gifu Prefecture (Text-figure 1). The age of 596×10^6 years (NOZAWA, 1964; measured by NAGASAWA) is one of the oldest dates among the granitic rocks in Japan (SATO, SHIRAHASE, and SHIBATA, 1967).

In spite of the repeated search for primary fossils that may indicate a spatio-temporal environment under which the conglomerate was deposited, only marine invertebrates ranging from Early Devonian to Late Permian have been found as derived fossils in the limestone gravels. Therefore, we were fortunate enough to discover an organo-sedimentary structure, supposedly of algal stromatolites in the

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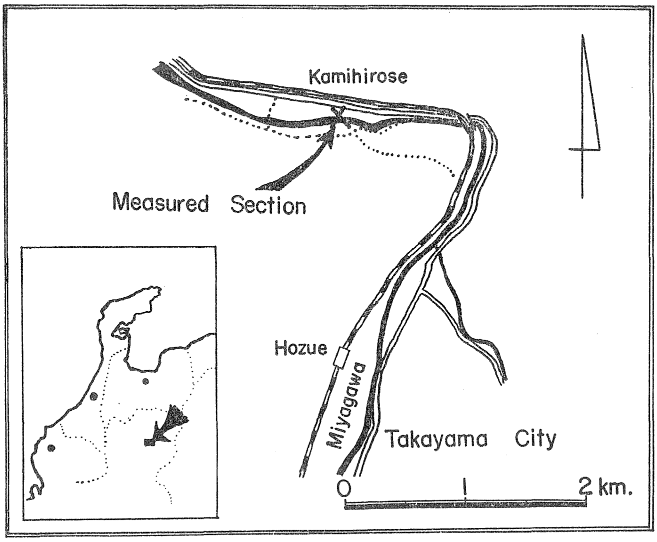
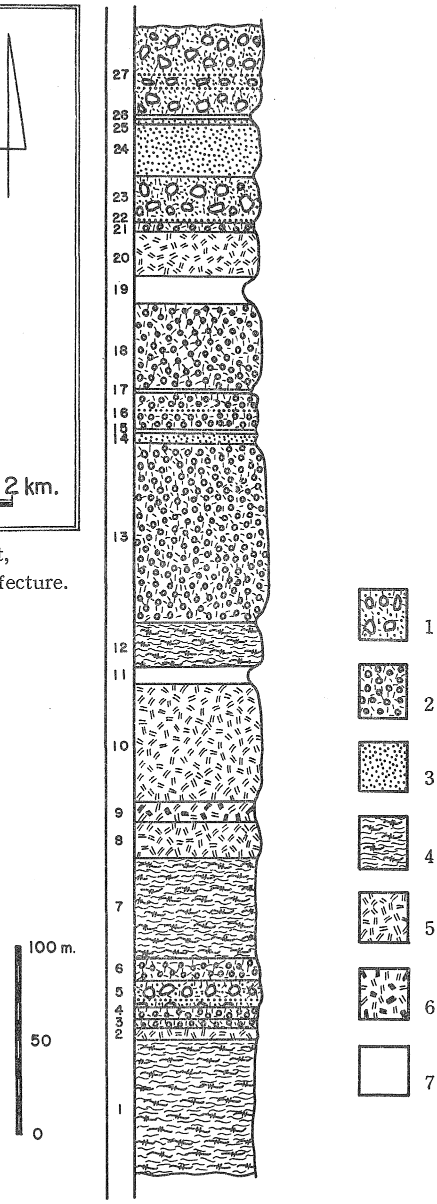


Text-figure 1. Index map of the Kamihirosé district, Kokufu-mura, Yoshiki-gun, Gifu Prefecture.

conglomerate cropping out near Kamihirosé. The conglomeratic beds have been treated under the name of the Kamihirosé formation by previous workers.

Kamihirosé Formation

The Kamihirosé formation is chiefly composed of conglomerate in association with sandstone and slate (NISHINO, 1946), besides greenstones. It is in fault contact with the black shale and sandstone of the Permian Moribu formation on the south side and with the schistose greenstones of the Carboniferous Arakigawa formation on the north side. The Funatsu granodiorite of Early to Middle Triassic intruded into the Kamihirosé formation at the northwest of Kamihirosé (NOZAWA and ISOMI, 1956). The formation strikes N 35° to 54° E and dips steeply (77° to almost 90°) to the southeast. It appears to exceed more than 650m in thickness, but the accurate thickness cannot be determined due to poor exposure.



Text-figure 2. Partial section of the Kamihirosé formation, measured along the banks of the Miyagawa.
1, boulder conglomerate;
2, pebble conglomerate;
3, sandstone;
4, greenstone, fine-grained;
5, greenstone, with white phenocrysts;
6, greenstone, with black phenocrysts;
7, unexposed.

As the result of stratigraphic measurement along the Miyagawa running near Kamihirosé, a part of the formation was divided into 27 units, and the clastic ratio was calculated to be 51%. In this partial section of some 600 m in thickness, the formation is composed of greenstones (49%), conglomerates (44%), and sandstones (6%). Besides, siltstones and slates are interbedded as thin layers in the sandstones. A detailed description of the measured section is given in Table 1 and Text-figure 2.

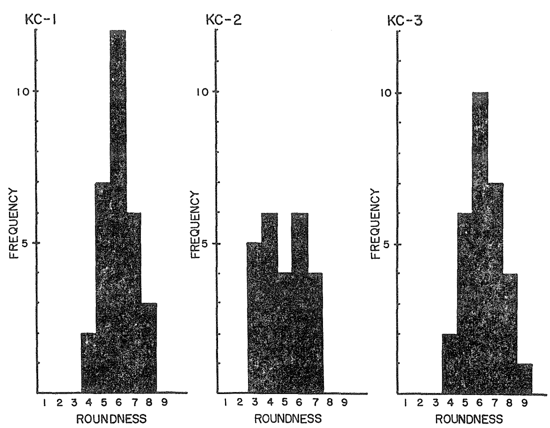
Table 1 Partial section of the Kamihirosé formation

(along the banks of the Miyagawa, north of Takayama City; measured by K. KONISHI and A. ÔMURA, Nov. 22–23, 1964)
Triassic (?)

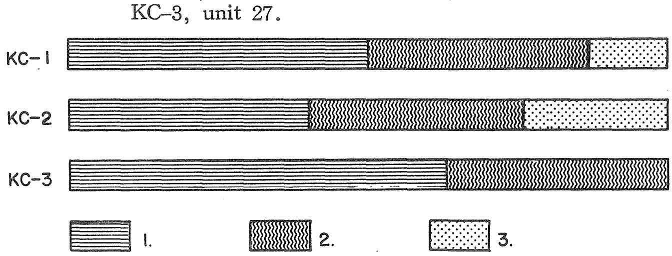
Kamihirose formation (in part)	Thickness (meters)
27. Conglomerate, contains boulders, about 100cm. in maximum diameter and about 20cm. in average diameter, of granite, granodiorite, quartz porphyry, volcanic rocks and shale, intercalates layers of shale and sandstone which contain fine pebbles, matrix fine-grained greenstones, very compact and resistive to weathering on the whole.	50+
26. Unexposd.	1
25. Sandstone and shale; sandstone, gray to dark gray colored, medium to coarse grained; shale, being intercalated in the middle part of sandstone, black colored.	1
24. Sandstone, very coarse grained, contains rarely fine pebbles, dark grayish colored, considerably compact, intercalates several layers of siliceous rocks which are reddish.	27
23. Conglomerate, contains cobbles, about 15cm. in average diameter, of granitic rocks and others, matrix very compact fine-grained greenstone.	24
22. Sandstone and siltstone; sandstone, pale gray to gray, coarse grained; siltstone, cross-laminated, dark gray, scour-and-fill structure.	0.7
21. Conglomerate, contains cobbles or pebbles, about 3 to 4 cm. in average diameter, matrix fine-grained greenstone.	4
20. Greenstone, brecciated, green to dark greenish colored, very massive and compact.	24
19. Unexposed.	15
18. Conglomerate, contains boulders rarely more than 20cm. in diameter and cobbles about 4cm. in average diameter, matrix fine-grained greenstone.	46
17. Unexposed.	1
16. Conglomerate, the same as unit 18, intercalates layers of sandstone, 50cm. in thickness, medium to coarse grained, and shale, black colored, being observed grading in sandstone.	19
15. Unexposed.	1
14. Sandstone, gray, medium to coarse grained, very compact, well-sorted.	5
13. Conglomerate, contains cobbles, 5 to 7cm. in diameter of granitic rocks, volcanic rocks, sandstone and limestone, matrix fine-grained greenstone.	98
12. Greenstone, fine-grained, very compact and massive.	24
11. Unexposed.	9
10. Greenstone, coarse grained, very compact and massive, contains white phenocrysts (4 to 5mm. in maximum diameter).	62
9. Greenstone, compact and massive, coarse grained, contains black phenocrysts (about 6mm. in maximum diameter).	11

8.	Greenstone, the same as unit 10.	19
7.	Greenstone, fine-grained, very compact, well-jointed.	53
6.	Conglomerate, contains subrounded to subangular and well-sorted cobbles, about 5cm. in diameter of granitic rocks, volcanic rocks and limestone, matrix fine-grained greenstone, compact.	12
5.	Conglomerate, contains boulders of granitic rocks, limestone, volcanic rocks and sandstone, intercalates layer of sandstone in the middle part; "*Collenia*"-type stromatolites in the uppermost part; fusulinids and other fossils were found in limestone cobbles of this unit.	14
4.	Conglomerate, the same as unit 6.	6
3.	Conglomerate, contains mostly volcanic rocks as fine pebbles.	4.5
2.	Greenstone, very massive and compact, coarse grained, contains phenocrysts being about 4mm. in diameter.	7.5
1.	Greenstone, fine grained, compact, massive on the whole, partly well-jointed.	70+
	Total thickness	608.7+

The granitic rocks, porphyrites, andesite and limestones are the main rock types in the gravels of the conglomerates as a whole. Through the detailed petrographic studies, the cobbles of granitic rocks have been divided into coarse-grained leucocratic and pink granite to trondjemite, schistose to gneissose migmatitic granodiorite,



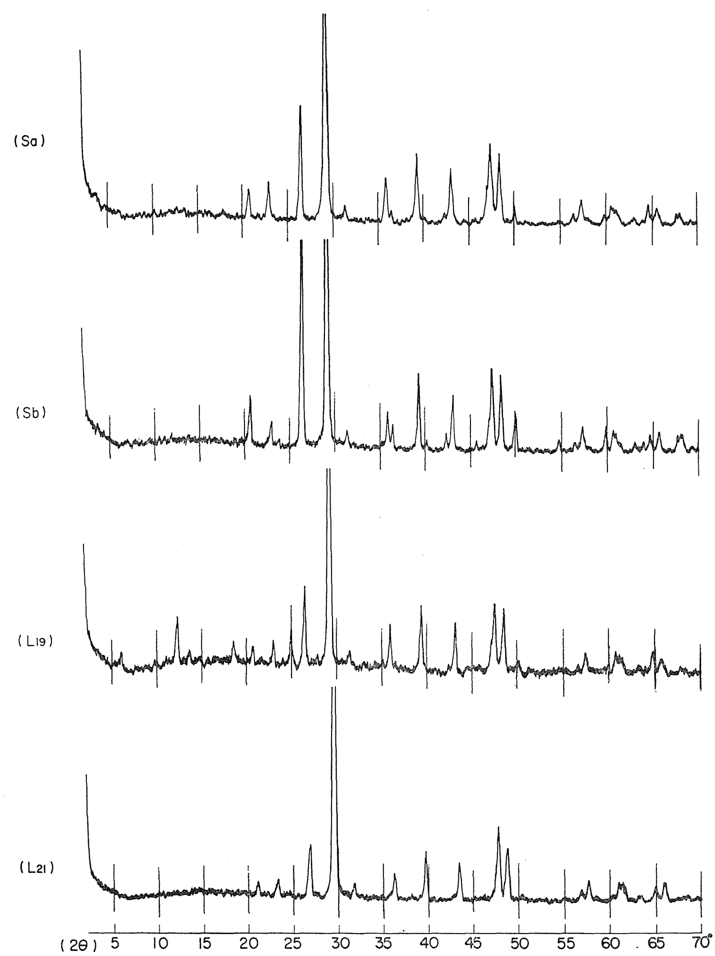
Text-figure 3. Histograms of roundness distribution as measured from 30 gravels at three units of the Kamihirose formation (by KRUMBEIN's silhouette method). KC–1, unit 5; KC–2, unit 13; and KC–3, unit 27.



Text-figure 4. Composition of rock types in 30 gravels at three units of the Kamihirosé formation. 1, Plutonic rocks; 2, Porphyritic rocks; and 3, Sedimentary rocks. Other symbols refer to text-fig. 3.

fine-grained and porphyritic granodiorite, graphic granite, mylonitic granodiorite, and aplite by NOZAWA (ISOMI and NOZAWA, 1957) and KANO (1962). Abundance analysis of roundness and rock types for some 30 gravels in each one meter grid at outcrop was carried out for three units, 5, 13, and 27, selected at random from the measured section. The roundness was determined with the aid of silhouette method by KRUMBEIN (1941). The results are shown in Text-figures 3 and 4. Sedimentary rocks apparently tend to decrease rapidly in both size and number upwards. In fact, no limestone gravels were found in the unit 27.

The limestone cobbles and pebbles are seen in the units 5, 6 and 13, and are exclusively composed of calcite and quartz without any trace of dolomite (Text-figure 5), and are divided into four types in the field; 1) saccharoidal marble containing white to yellowish white breccias of granule size in pink matrix (Sa), 2) fine-grained marble in which black and white patches are irregularly interwoven (Sb), 3) dark

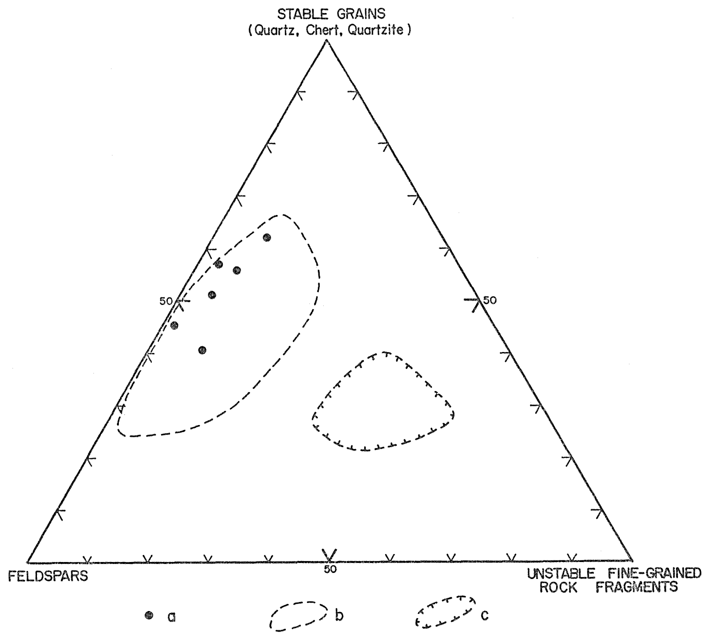


Text-figure 5. X-ray diffraction patterns of limestone cobbles of the Kamihirosé formation; scans from 2° to 70° 2θ (Cu $K\alpha$). For symbols refer to the text.

gray, very fine-grained crystalline limestone ('calcilutitic') cut by white calcitic veinlets (L-19), and 4) finely saccharoidal crystalline limestone in which black to dark purple specks of sand-size are scattered in the pale pink to grayish white matrix (L-21). Although crinoidal stem-joints have been found in the type 3, almost all the fossils have been found exclusively in the type 4. Even the last type of limestone has been deformed and recrystallized considerably. Crinoid stems, bryozoans, fusulinids, gastropods, dasycladads(?) and others have been found, but they are too poorly preserved to be identified in even the generic rank. The most allochems are öolites and fossil fragments, thus the limestones may be termed as either öosparite or biosparite (Plate IV), according to the nomenclature by FOLK (1962). A large number of the limestone gravels shows cataclastic texture under the microscope. A black colored mineral similar to graphite is recognized around the fragments of fossils and öolites, often in the form of microstylolite, as if it suggests an original rock rich in carbonaceous and argillaceous material. The disposition of the preferred orientation of the long axes in the flattened öolites and elongated fragments of fossils is so different for each gravel, that the fossiliferous limestone must have undergone to regional metamorphism before the deposition of the conglomerates.

The sandstone of this formation is pale greenish gray and varies from fine to very coarse in grain size with a moderate degree of sorting. The grains are subangular to subrounded. Argillaceous matrix occupies more than 20 % in the volume. The grains are composed of quartz, potash feldspars, and plagioclase (now altered to albite), and partly of pyroxene, hornblende and magnetite. Calcite in cement and sericite, kaolinite (at least partly), and chlorite are believed to have formed secondarily. Quartz grains are the largest in diameter and show the wavy extinction. Fragments of andesitic rocks are rarely met with. Feldspars have been altered partly to sericite, kaolinite, and chlorite. The modal analysis of the sandstones from six units was carried out with the SWIFT point counter, and the result is summarized in terms of the classification scheme of GILBERT (1955) as shown in Text-figure 6. The close similarity between the sandstones of the lower member of the Motodo formation (ÔMURA, 1966, MS) and those of the Kamihirosé is obvious, and both may be termed as arkosic wacke. The shales of this formation are dark gray to black, and composed of quartz, feldspars, calcite, illite, kaolinite, and Fe-chlorite, as examined by the X-ray diffraction method.

The greenstones are very compact and massive except for the portions well jointed, alternate conformably with sandstones and conglomerates, and are referred to andesitic lava flows and tuff. They lack schistosity at all, the character differing from the greenstones of the Carboniferous Arakigawa formation. Plagioclase (now albite), potash feldspars, and augite are recognized among the phenocrysts, most of which have been altered to chlorite and sericite. Actinolite, epidote, and albite are common constituents and can be interpreted to be secondary in origin. The groundmass is chiefly composed of lath-shaped plagioclase and in parts pyroxene.



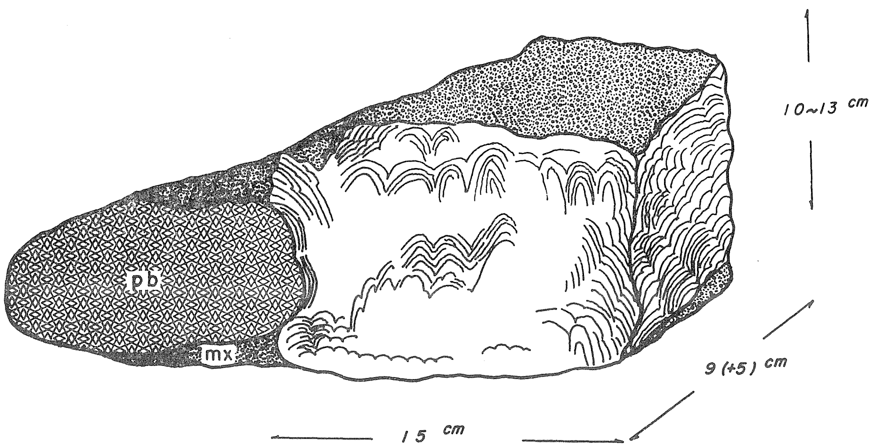
Texr-figure 6. Three component composition diagram of impure sandstones (or wacke) from the Kamihirosé formation in comparison with those of the Motodo formation. (classification scheme is after GILBERT, 1955) a, Kamihirosé formation; b, Lower Member of the Motodo formation; and c, Upper Member of the same formation.

Fragments of cherty rocks and worn grains of quartz are also recognized in the rocks probably tuffaceous in origin.

Like other equivalents, the age assignment of the Kamihirosé formation has been a controversial issue among the geologists working in the Hida Mountainland; the following three opinions have been offered in the publications, 1) Jurassic or Jurasso-Cretaceous, as a member of the Tetori Group (SHIBATA, 1954; KAMEI, and IGO, 1956), 2) Triassic, as a formation to predate the Tetori Group (NISHINO, 1946), and 3) Carboniferous, as a member of the Carboniferous Arakigawa formation (ISOMI and NOZAWA, 1957). The fourth, yet close to the second, interpretation can be possible that the formation may be compared with the Kuman series of the Late Permian, because of the occurrence of the so-called Usuginu-type conglomerates. KANO (*ibid.*) suggested a composite nature of the formation from his petrographic study. Based on the field evidences so far available and the interpretations based on them, the present authors are of the opinion that the Kamihirosé formation is placed at some interval between the Latest Permian to Late Triassic. Find of microfossils which can be time indices is being encouraged for the slaty beds of the formation.

Algal Stromatolites

The algal stromatolites described here were collected from the uppermost part of the conglomerate (unit 6 in the columnar section) along the Miyagawa. Because a rounded cobble of granite in fist size is partly encrusted with the algal stromatolites, they should have been growing during the deposition of the conglomerate (Text-figure 7; Pl. I, fig. 2). The apparent top-and-bottom relation deduced from the growth form of



Text-figure 7. Sketch diagram showing the mode of occurrence of the Kamihirosé algal stromatolites. pb, cobble; mx, matrix of the conglomerate.

the stromatolites does not coincide with that determined by graded bedding and cross laminations observed in the overlying unit 16. This may be interpreted that the stromatolites partly enclosing the cobble were detached from the growing site, probably rotated and transported in a short distance, and buried at nearby bottom floor.

Algal stromatolites are one of the major organo-sedimentary structures common in carbonate rocks throughout the geologic columns from Precambrian to Recent, and particularly abundant in tha Cambrian and Ordovician formations. In Japan where the formations of these periods have not been proven to occur, the onkolites of *Pycnostroma*-type described by the senior author (KONISHI, 1959) from the Nezu member of the Nabeyama Limestone at Kuzuu, Tochigi Prefecture are the only described example of this type of organo-sedimentary structure. While the algal stromatolites seem to have a little value as index fossils, they are recognized as well-established facies-fossils (*e.g.*, REZAK, 1957; GINSBURG, 1960).

Algal stromatolites are aggregates of a number of species taxonomically divergent and the mode of their growth as gross morphology in fossils is chiefly controlled by the environment. Therefore, the application of the classification and nomenclature based on the traditional binomial system to the algal stromatolites have been doubted by several workers, whereas a great number of form genera and species has been introduced to science, among which two celebrated 'genera' *Collenia* and *Cryptozoon* are representatives most familiar to geologists. Recently, LOGAN, REZAK and GINSBURG (1964) advocated a new classification of algal stromatolites founded on the arrangement of basic geometric units which are believed to reflect the environmental conditions at the site of growth, an induction from the observations on the living algal stromatolites. The following description is essentially based on their classification.

The algal stromatolites of the Kamihirosé formation are 10 to 13 cm in height, 15 cm in breadth, and 9cm in width. They are classified as LLH-type (laterally linked hemispheroids) or so-called *Collenia*-form as a whole. However, they are composite in structure and can be divided into three successive parts. Thus, this compound structure may be formularized as follows;*

LLH-C ——→ SS-C → LLH-S ——→ LLH-C → SH-C (macrostructure)
(unit *a*) (unit *b*) (unit *c*)

LLH-C (microstructure)

As seen in the formula, the basal unit *a* varying the thickness from 2.5 cm to 3.5 cm initially starts with rhythmic alternation of quartzose and calcitic layers of some few mm thick, both being in a microstructure of LLH-C, with occasional intervention of strongly convex and almost discrete space-linked spheroids of about 2mm in thickness (Pl. III, fig.1). The top of this unit as well as the bottom is partly contorted and fragmented, and is overlain with the concentrically stacked spheroids (SS-C), which are vertically elongated and 1.5 ~ 2.5 cm in diameter, the basal member of the unit *b*. The layer of the spheroids passes into those of continuously space-linked hemispheroids with finely laminated microstructure. The layers attain 1.5 ~ 2.0 cm in thickness. The unit *b* is terminated with the thin veneer of clayey material 0.5 mm thick (shown as the zig-zag line coming down from the NE corner of Fig. 2 of Plate II; also Fig. 2 of Pl. III). The succeeding unit *c* consists of the mats of LLH-C about 0.4 cm thick which grow into the vertically stacked pillars of SH-C in varying diameters (0.5 ~ 1.0 cm).

The stromatolites are mostly white except for the black to grayish black irregular patches 1 to 2 cm in diameter, both are composed of calcite and quartz with

* Notations used in the formula are after LOGAN, REZAK and GINSBURG (1964).
LLH-C, close lateral linkage of hemispheroids;
LLH-S, spaced lateral linkage of hemispheroids;
SH-V, vertical stacked hemispheroids, with variable basal radius;
SH-C, vertical stacked hemispheroids, with constant basal radius;
SS-I, inverted stacked spheroids;
SS-R, randomly stacked spheroids; and,
SS-C, concentrically stacked spheroids.

appreciable amount of clay minerals. The partial analysis of both the white and black portion indicates that silica is enriched in the white (gray in Fig. 2 of Pl. II; (b) in Table 2) part.

Table 2. Chemical analyses of LLH-type stromatolites.
(a), dark colored portion
(b), light colored portion

	(a)	(b)
SiO_2	15.44	28.03
Al_2O_3	0.24	0.37
Fe_2O_3 / FeO	} 0.46	} 0.37
CaO	45.89	39.32
MgO	0.27	0.19

In order to refine a general conclusion drawn from a conventional stratigraphic analysis on the conglomeratic formations characterized with red bed associations, the stromatolites from the Kamihirosé formation and the dolostone lens in the Motodo formation should be taken into consideration. Although red beds may "appear to be overwhelmingly more common in non-marine than in marine sedimentation" (KRUMBEIN and SLOSS, 1963), scores of examples of marine red beds can be combed out from the previous reports. Paleoclimatic implication of red beds which has been adopted by SCHWARTZBACH (1963) and others to diagnose hot climates may not be as simple as they believe (VAN HOUTEN, 1964). As to be discussed elsewhere in a separate paper, the dolostone lens composed of ferroan dolomite, kaolinite, illite, quartz, and pyrite, and preserving desiccation breccias can be interpreted as the evaporation residue left in a small ephemeral pond where water was saline. Either the sediments or stromatolites cannot determine the salinity range of water under which the formations were deposited. The useful information which the Kamihirosé stromatolites can supply may be the depth range of the sedimentation.

It has been pointed out by CLOUD (1942) and others that algal stromatolites occur in very shallow fresh or saline water environments. LOGAN, REZAK and GINSBURG (*ibid.*) are of the opinion that their LLH-form (or *Collenia*-form) stromatolites are "characteristically developed in continuous mats and algal-bound sediments from the marine, intertidal mud-flat environment, mainly in the protected locations of re-entrant bays and behind barrier islands and ridges where wave action is usually slight" (LOGAN *et al.*, *ibid.*). Although the compound structure preserved in the stromatolites may be interpreted as the evidence of minor changes in the physical environments, therefore, the Kamihirosé stromatolites are presumed to have formed under an environment similar to the ones as quoted above, in a littoral zone. They were probably detached and broken from the site of the growth by the episodically turbulent waves and streams accompanying influx of a large quantity of terrigenous and possibly volcanic materials from an adjacent river, and were displaced and redeposited in a nearby deeper, but probably very shallow sublittoral environment. The sedimentary features such as gross lithologies, cross-bedding and scour-and-fill, which occur in the overlying beds do not contradict with this interpretation.

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PLATE I

Explanation of Plate I

Stromatolites from the Kamihirosé Formation (1)

Figure 1. Photograph showing the occurrence of the algal stromatolites; the hammer is placed in parallel to the strike of unit 5, boulder conglomerate, and is about 30 cm. in length.

Figure 2. The gross morphology on the weathered surface of the *Collenia*-type algal stromatolites and their contact relationship to the pebble (at the left end of the picture).

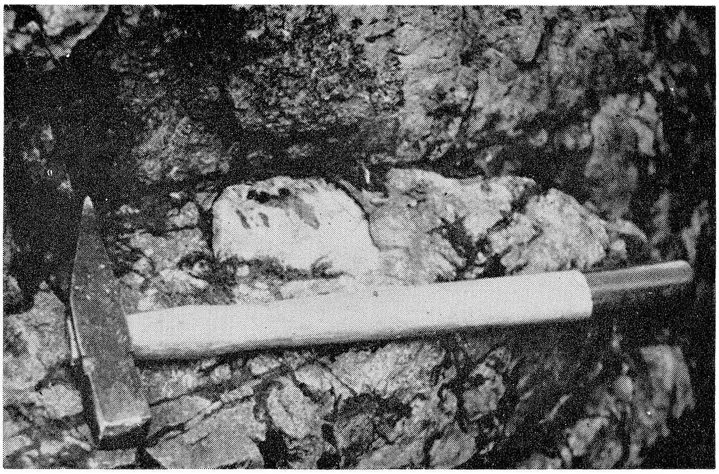

Figure 1

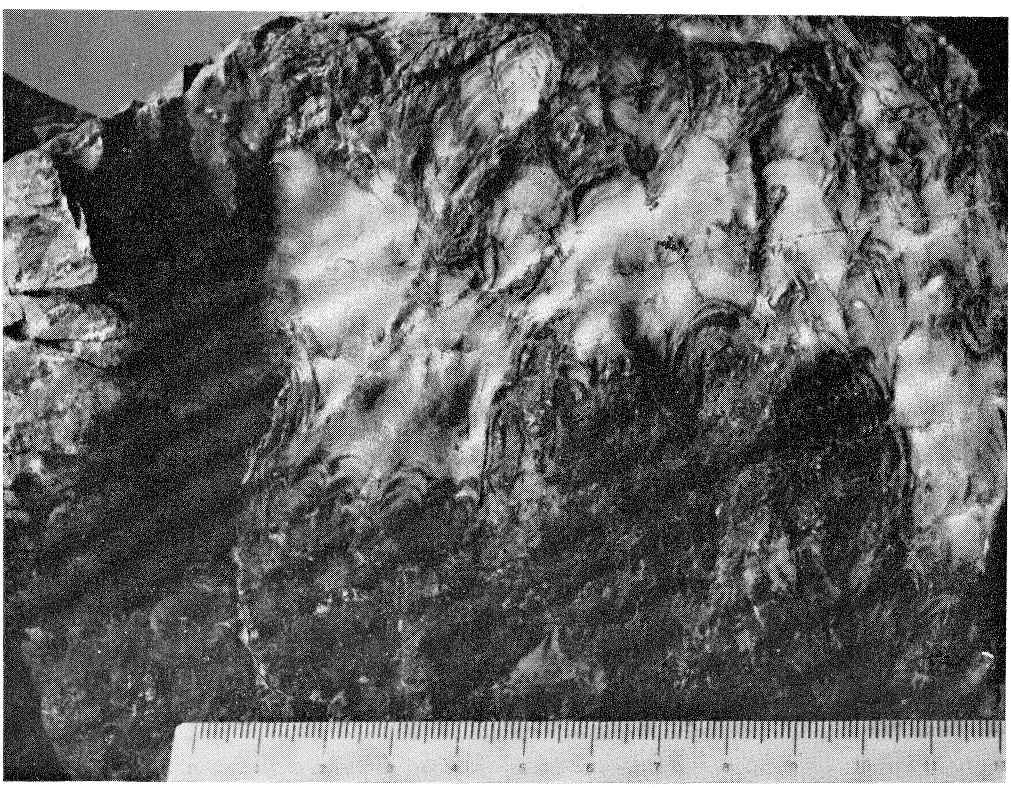

Figure 2

PLATE II

Explanation of Plate II

Stromatolites from the Kamihirosé Formation (2)

Figure 1. A closeup view of the weathered surface showing vertical section of cylindroids.

Figure 2. Photograph showing the thin slide from the same vertical section; taken with transmitted unpolarized light but printed in reversal tone. GKZ Reg. No. 13976.

Figure 1

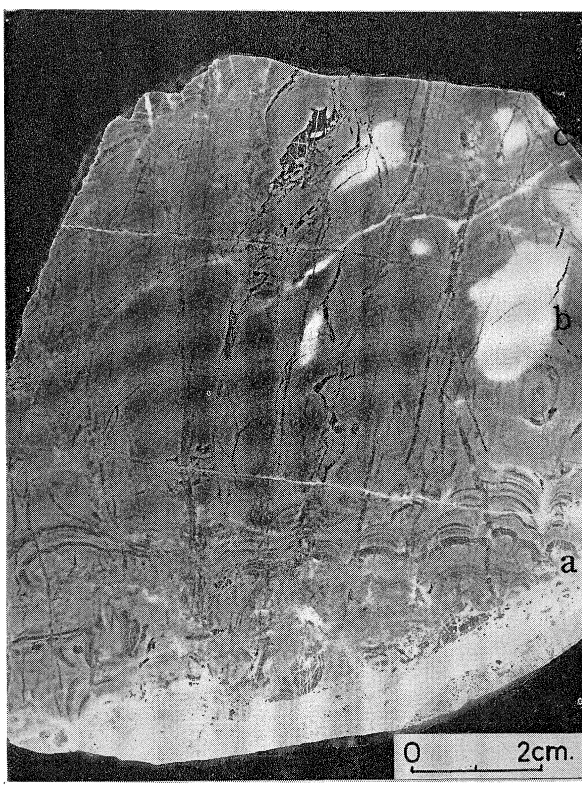

Figure 2

PLATE III

Explanation of Plate III

Stromatolites from the Kamihirosé Formation (3)

Figure 1. Photomicrograph showing the basal contact of the unit *a*, and details of the laminated structure. (GKZ Reg. No. 13976)

Figure 2. Photomicrograph showing the contact between the units *b* and *c*; notice the distinct difference in the structure and dimensions of the cylindroids between the two units. (GKZ Reg. No. 13976)

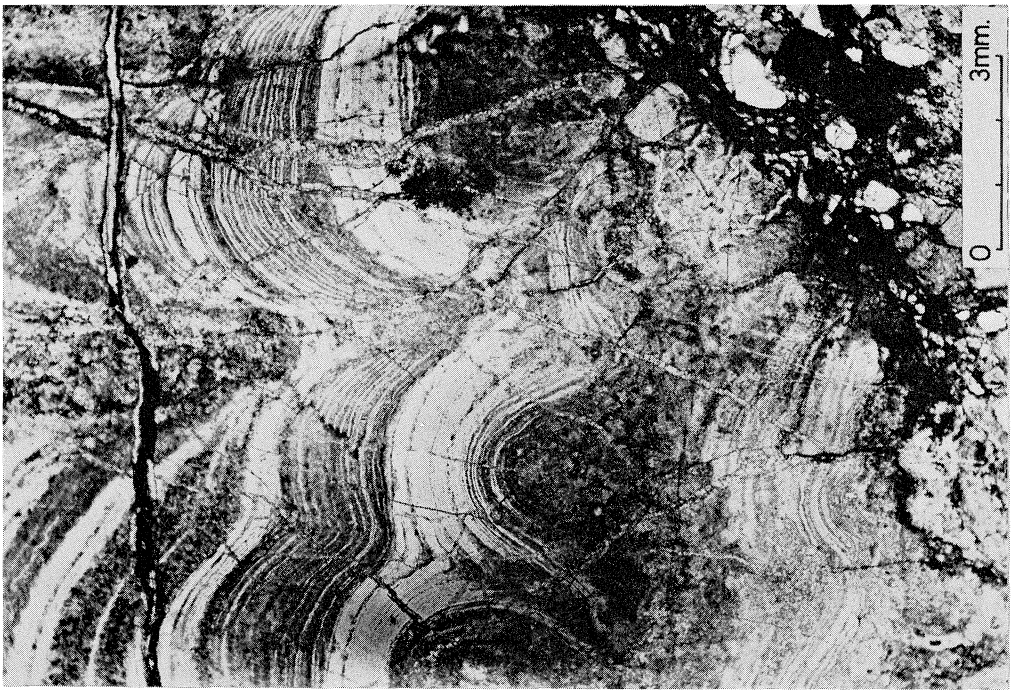

Figure 1

Figure 2

PLATE IV

Explanation of Plate IV

Fossils in limestone cobbles of the Kamihirosé Formation

Figure 1. Fusulinid (?) or Dasycladad (?) test, gen. et sp. indet., preserved in the crystalline öosparites.

Figure 2. Cataclastic microcoquina, with crinoidal debris and carbonaceous matrix.

Figure 3. Öosparite, with deformed öolites.

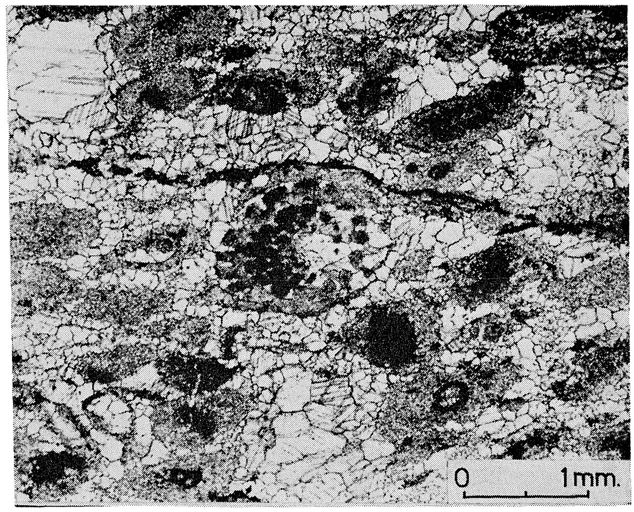

Figure 1

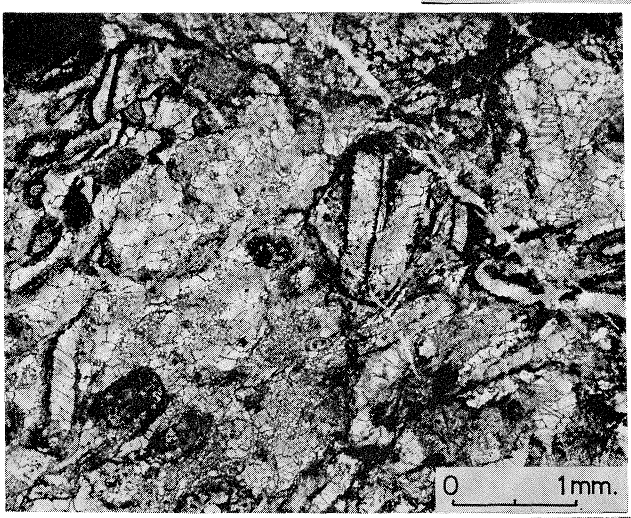

Figure 2

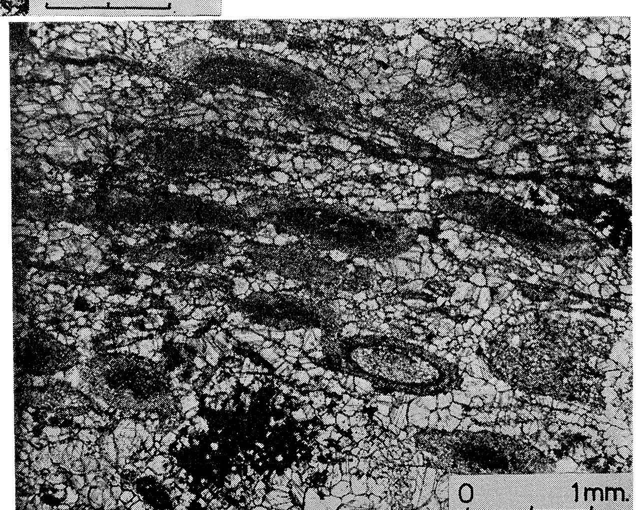

Figure 3