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The oldest record of microbial-caddisfly bioherms from the Early Cretaceous Jinju Formation, Korea: occurrence and palaeoenvironmental implications

In Sung Paik*

Department of Environmental Geosciences, Pukyong National University, Busan 608-737, Republic of Korea

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Abstract

Fossil microbial-caddisfly bioherms have been recently discovered in the Early Cretaceous lacustrine deposits (Jinju Formation) at Jahyeri, Korea. The Jahyeri deposits consist of shallow to marginal lake deposits in which medium- to fine-grained sandstone beds and silty mudstone beds are alternated and small-scale wave ripples and polygonal desiccation cracks are common. The microbial-caddisfly bioherms occur on and within oolitic sandstone and are also covered by oolitic sandstone, suggesting that the bioherms formed in shallow and turbulent water. The depositional condition of Jahyeri caddisfly bioherms is thus correspondent with the wave-washed and well-oxygenated biotope of modern lentic Trichoptera. By comparing the habitat, size and shape of cases, the composition of case-building particles, and case construction way, it seems likely that the Jahyeri caddisfly cases were those of the family Leptoceridae. The Jahyeri microbial-caddisfly bioherms are all that have been discovered throughout the Jinju Formation, and the Jahyeri bioherms are very small compared with the tall growth of the Eocene Little Mesa bioherms. The limited growth and occurrence of microbial-caddisfly bioherms in the Jinju Formation might have resulted from the predominance of clastic deposition in the Jinju Lake. The occurrence of Jahyeri microbial-caddisfly bioherms may reflect the development of a drought stage which resulted in a limited supply of clastic sediments into the Jahyeri Lake. The Jahyeri microbial-caddisfly bioherms have common features with modern and Tertiary microbial-caddisfly bioherms in that the colonial caddis cases constructed bioherms in cooperation with a benthic microbial mat. The similarity between the Jahyeri microbial-caddisfly bioherms and those from the Tertiary and modern deposits suggests that the physical environments of microbial-caddisfly symbiosis has changed little throughout the geologic time and space, and thus indicates that the microbial-caddisfly bioherms can be used to interpret paleohydrological conditions. This finding is the first report of fossil microbial-caddisfly bioherms in Asia and represents the oldest occurrence of microbial-caddisfly bioherms in the geological records.

Keywords: Early Cretaceous; Jinju Formation; Jahyeri; Lacustrine; Caddisfly; Bioherms; Korea

* Fax: +82 51 628 6432.
E-mail address: paikis@pknu.ac.kr.

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1. Introduction

Although fossil caddisflies are known from the Permian, their first records of larval constructions occurred in the Middle Jurassic (Ivanov and Sukatsheva, 2002). During the Late Jurassic to the Early Cretaceous the building abilities of caddisfly larvae evolved and numerous case parataxa appeared during the Early Cretaceous (Wootton, 1988; Jarzembowski, 1995; Ivanov and Sukatsheva, 2002). In modern, freshwater, fluvial environments some caddisfly cases build carbonate bioherms by incorporation with cyanobacterial mats (Humphreys et al., 1995; Drysdale, 1999; Janssen et al., 1999). However, discrete caddisfly-dominated bioherms are unknown from modern lakes (Leggitt and Cushman, 2001), and fossil caddisfly-built bioherms are very rare in the geological records. Fossil microbial-caddisfly bioherms are known only from the Eocene Green River Formation of USA (Bradley, 1924; Biaggi et al., 1999; Leggitt and Cushman, 2001) and the Limagne graben in the Massif Central of France (Hugueney et al., 1990; Bertrand-Sarfati et al., 1994).

All Early Cretaceous caddisflies collected have been discovered in Far-East Asia, including Transbikalia and Mongolia (Ivanov and Sukatsheva, 2002). However, fossil caddisflies have never been known from the Mesozoic deposits of Korea, NE China, and Japan. In this study fossil microbial-caddisfly bioherms were newly discovered from the Lower Cretaceous lacustrine deposits (Jinju Formation) of Korea (Fig. 1). This finding is thus the first report of Cretaceous caddisfly in this region and they represent the oldest occurrence of microbial-caddisfly bioherms in the geological records. The micro-

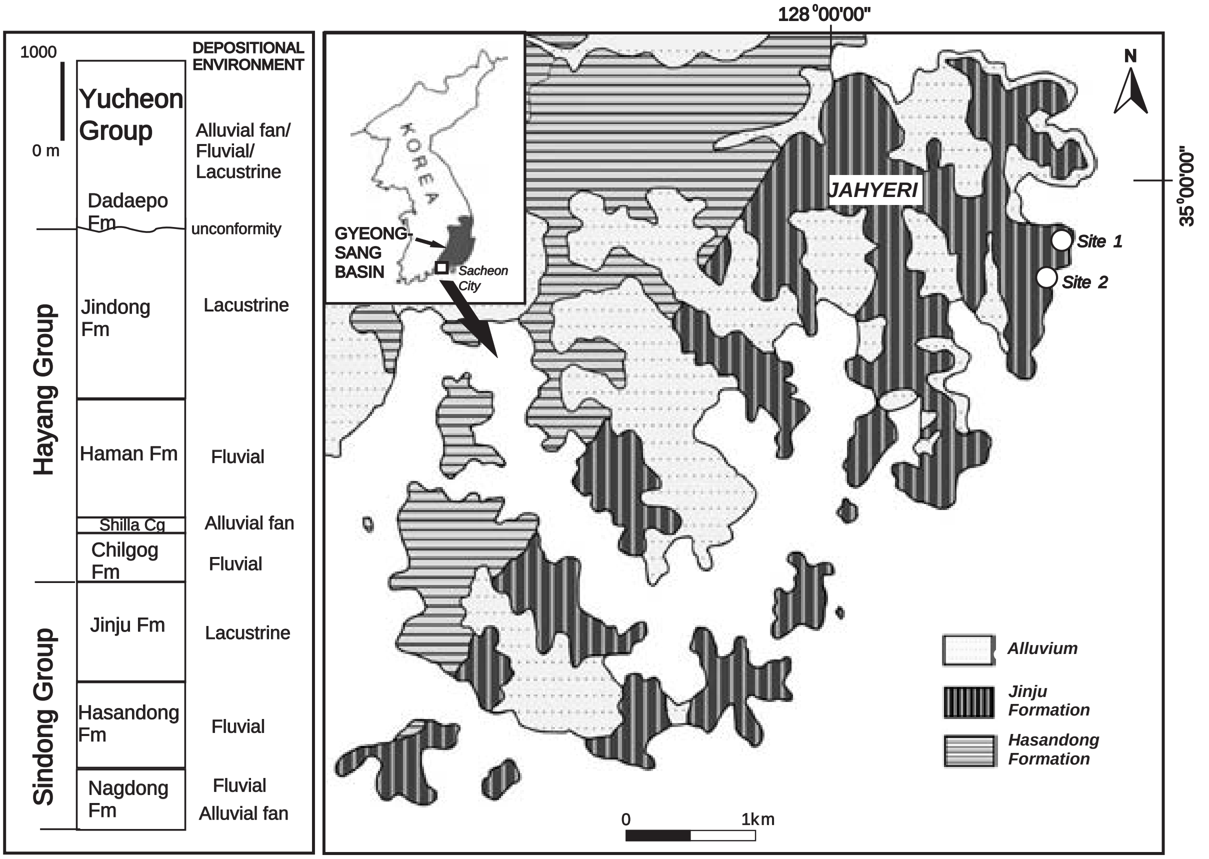


Fig. 1. Stratigraphy of the Gyeongsang Supergroup and location and geological map of study area.

bial-caddisfly bioherms of the Jinju Formation have common features with modern and Tertiary microbial-caddisfly bioherms in that the colonial caddisfly cases constructed bioherms in cooperation with benthic microbial mats, suggesting that the physical environments of microbial-caddisfly symbiosis have changed little throughout the geologic time and space.

In this study, the occurrence of fossil microbial-caddisfly bioherms from the Jinju Formation is described and their palaeoenvironments are interpreted. This study provides new evidence for understanding palaeoecology and evolution of the bioherm-building caddisfly and microbial-caddisfly symbiosis throughout geologic time.

2. Geological setting

During the Cretaceous a number of transtensional basins formed in South Korea (Lee, 1999; Chough et al., 2000), in which sedimentation was governed collectively by regional tectonism, climate, and volcanic activity (Choi, 1985). These basins are all non-marine and consist of alluvial fan, fluvial plain, lacustrine, and volcanic deposits. The Gyeongsang Basin is the largest one and consists of a 9000-m-thick sequence of deposits assigned to the Gyeongsang Supergroup, which is subdivided into the Sindong, Hayang and Yucheon groups, in ascending stratigraphic order (Chang, 1975). In the Gyeongsang Supergroup, body fossils are not abundant, but invertebrate trace fossils and dinosaur tracks are common. During the Cretaceous, the Korean Peninsula was situated in mid-latitudes as it is today (Lee et al., 1987; Kim et al., 1993). Based on fossil records, palaeosols and lithology (Paik and Kim, 1997, 2003), the general palaeoclimatic regime of the Gyeongsang Supergroup has been interpreted to have been warm and dry.

The Jinju Formation, in which fossil caddisfly bioherms occur, lies in the upper part of the Sindong Group which generally has been assigned to the Lower Cretaceous by charophytes (Seo, 1985), spores and pollen (Choi, 1985), and palaeomagnetism (Doh et al., 1994). The Jinju Formation is underlain by the Hasandong Formation (fluvial deposits) and overlain by the Chilgok Formation (fluvial deposits). The Jinju Formation is a lacustrine deposit consisting mainly of dark grey to black mudstones and shales and sandstones. The interval between the lowerlying Hasandong Formation and the Jinju Formation in the study area displays a passage from a fluvial plain facies association consisting of floodplain, levee, crevasse splay and channel facies to a lacustrine facies association composed of crevasse splay, channel, overbank sheet splay, marginal lake, open lake and stream mouth bar facies (Choi, 1986). In this non-deltaic lacustrine association, shallow marginal lake deposits including channel facies are gradually replaced upwards by deeper open lake deposits made up of open lake and stream mouth bar facies (Choi, 1986). Volcanic detritus are commonly contained in the upper half of the Jinju Formation (Choi, 1986; Noh and Park, 1990).

In the Jinju Formation, body fossils including ostracods, bivalves, estherids, insects, fishes, and some dinosaur and pterosaur teeth are contained in fine-grained deposits, and stromatolites sporadically occur. Diverse orders of insects were collected from the Jinju Formation including Orthoptera, Homoptera, Mantodea, Diptera, Coleoptera, Hymenoptera, Dermaptera, Neuroptera, Blattoidea, Hemiptera, Odonata, Mecoptera, and larvae of aquatic insects (Lee et al., 2001). Plant fossils and invertebrate trace fossils are common, and dinosaur tracks are observed in places in the Jinju Formation.

3. Caddisfly bioherm-bearing deposits

The sedimentary deposits bearing fossil caddisfly bioherms are exposed along the coast of Jahyeri, Sacheon City (Fig. 1). In general, they consist of an alternation of medium- to fine-grained sandstone beds and silty mudstone beds (Fig. 2). The sandstone beds are usually tabular and thin- to medium-bedded. Planar- to cross-laminations are common (Fig. 3A), and penecontemporaneous deformation structures are present. Small-scale wave and current ripples are commonly observed on the surfaces (Fig. 3B). Interference ripples are also present. The orientations of ripples vary slightly. In places, lenticular sandstone beds of channel or splay deposits with erosive bases occur (Fig. 3C). Intra-

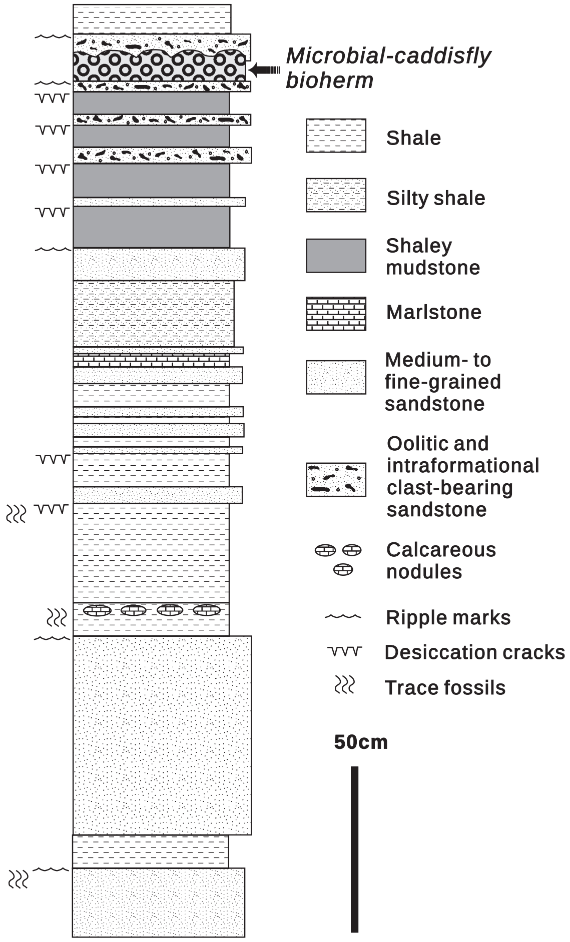


Fig. 2. Stratigraphic section of Jahyeri microbial-caddisfly bioherm-bearing deposits at site 1.

formational mudstone clasts and carbonized wood fragments are common and ooids are present in the sandstones. Oolitic packstone to grainstone beds and peloidal packstone to grainstone beds occur in the upper part of the bioherm-bearing deposits. Pebble- to cobble-size intraformational fragments of stromatolite are scattered in the overlying and underlying beds of fossil caddisfly bioherms (Fig. 3D). Some of the vertebrate bone fragments are contained in these coarse-grained deposits. The sandstones are usually cemented with calcite. Granular calcite cements and calcite aureoles around the detrital grains are observed.

The mudstones beds are also thin- to medium-bedded and generally dark grey. Polygonal desiccation cracks are common in the mudstone (Fig. 3E), and ichnofossils are present in places (Fig. 3F). The mudstones are usually calcareous and contain calcrete nodules. Some calcrete nodules formed selectively along the desiccation cracks. Circumgranular cracks and fitted peloids, indicative of pedogenic origin (Read, 1976; Freytet and Plaziat, 1982; Esteban and Klappa, 1983), are common (Fig. 3G) in the mudstone. One laminated packstone associated with mudstone also shows pedogenic feature. The ooids in the laminated packstone are superficial and have peloidal nuclei. In this packstone, subcircular to ovoid micrite glaebules occur in fitted contact with adjacent glaebules (Fig. 3H). Some of these glaebules have been discreted into peloids, and some of the peloids have developed into superficial ooids. Such occurrence indicates that the calcrete ooids originated from micrite glaebules, and that the packstone texture is not depositional fabric but pedogenic fabric. Thin laminar calcretes along desiccation cracks are associated with this laminated oolitic packstone. In the pedogenic mudstone, an aggregate of subcircular calcispheres are observed. Peloidal calcretes usually formed pedogenic packstone.

4. Caddisfly bioherms

The fossil caddisfly bioherms are found at two sites (Fig. 1). At site 1 the bioherms are exposed with other deposits, and at site 2 a single small bioherm occurs as isolated rock on a modern tidal flat.

4.1. Site 1

Two patch bioherms about 12.5 m apart are observed at site 1. They are exposed as small domes with rugged and smooth surfaces. One is about 7 m wide and 0.3 m high (Fig. 4A), and the other is about 1.5 m wide and 0.3 m high (Fig. 4B). These bioherms formed on and within oolitic sandstone and are also covered by oolitic sandstone (Fig. 2). Apparently, the bioherms consist of columnar and rod-shaped stromatolites. The orientation of the long axis of the columns and rods vary from subhorizontal to subvertical. Most of the rods are subhorizontal and most of the columns are subvertical. One rod-shaped stromatolite reaches 5 m

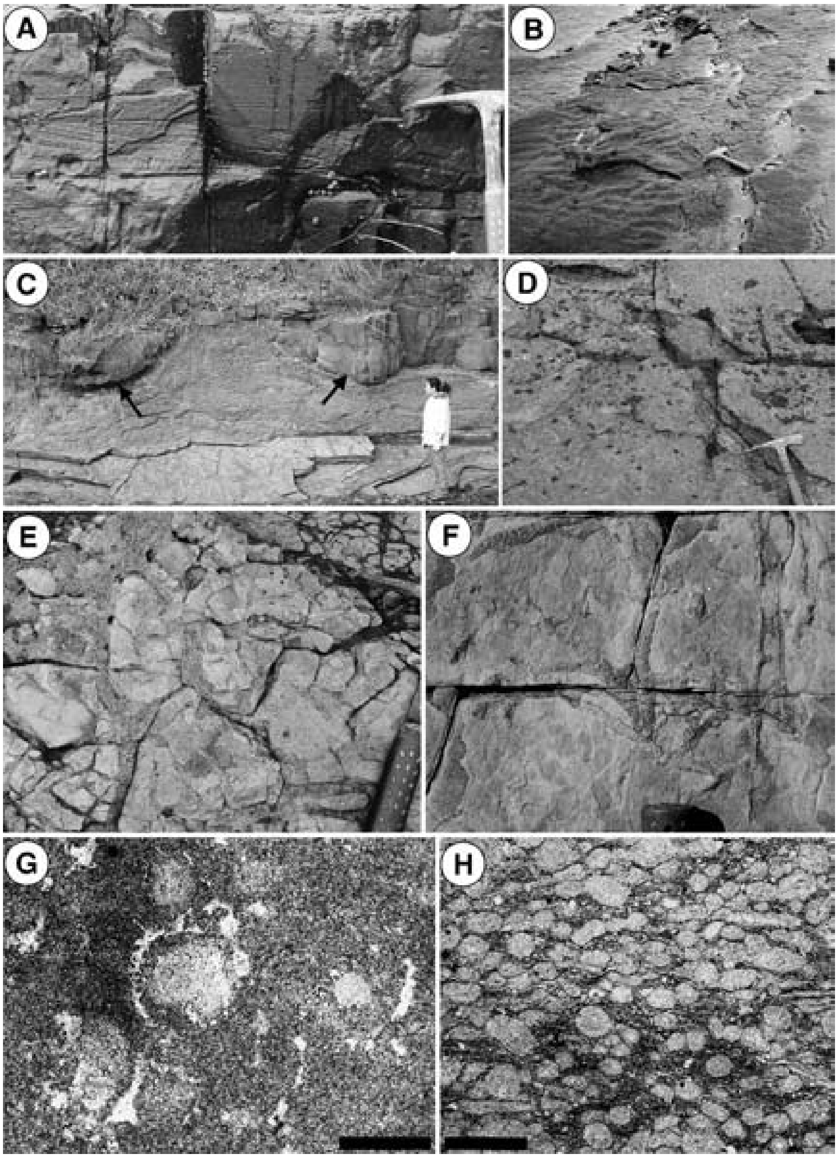


Fig. 3. Occurrence of the microbial-caddisfly bioherm-bearing deposits at site 1. (A) Planar- to cross-lamination in medium-bedded sandstone. (B) Bifurcated wave ripples on medium- to fine-grained sandstone beds. (C) Crevasse channel deposits (arrows) on marginal lake deposits. (D) Intraformational stromatolite fragments in calcareous sandstone. (E) Polygonal desiccation cracks on mudstone bed. (F) Invertebrate trails and burrows on mudstone bed. (G) Circumgranular cracks in mudstone. Thin-section photomicrograph. Scale bar is 0.2 mm. (H) Pedogenic packstone formed in mudstone. Thin-section photomicrograph. Scale bar is 0.5 mm.

in length (Fig. 4C). Each column and rod is laterally juxtaposed or discrete. The external surfaces of the stromatolites are bulbuous or botryoidal (Fig. 4D).

Internally, most of the stromatolite columns and rods have cores of colonial caddisfly cases (Fig. 5A,C). The colonial growth of caddisfly cases on partially eroded stromatolites or stroamtolite fragments is observed within these cores (Fig. 5C). Some of rod-shaped stromatolites do not have caddisfly cases but log-shaped cores. In general, several small stromatolite columns (more or less than 10 cm in

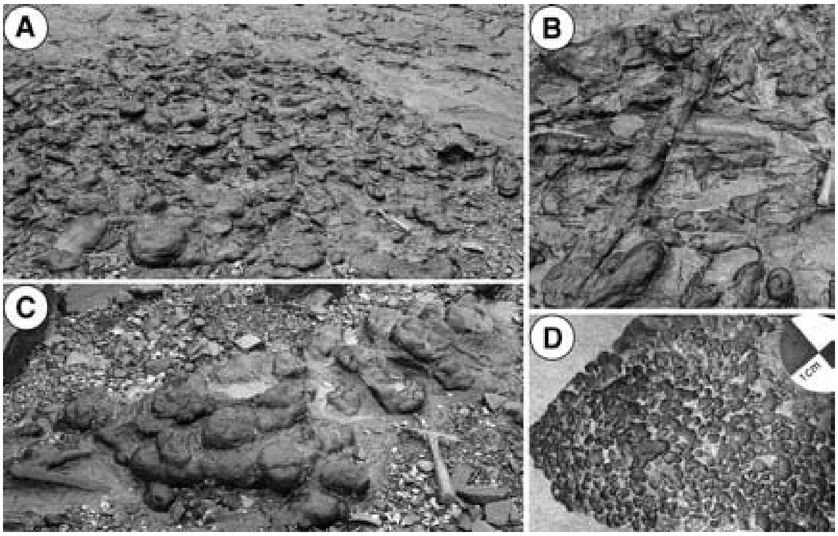


Fig. 4. Occurrence of Jahyeri microbial-caddisfly bioherm at site 1. (A) Overall view of the larger bioherm with bulbous surface. (B) Rod-shaped stromatolite (arrow) in the larger bioherm. (C) Overall view of the smaller bioherm. (D) Botryoidal surface of stromatolite of the larger bioherm.

diameter) with cores of colonial caddisfly cases are bound together forming larger stromatolite columns (a few tens of centimeters in diameter and more or less than 2 cm in thickness) (Fig. 5B). Caddisfly cases also occur between the small and large columns (Fig. 5B). Three successive layers of colonial caddisfly cases forming terraces occur within one larger stromatolite column (Fig. 5D). In places, fragmented and rebounded stromatolite columns are observed (Fig. 5E). Caddisfly cases also occur on these fragmented columns.

The caddisfly cases are usually arranged in regular arrays of parallel, subvertically to subhorizontally aligned cases (Fig. 5F,G) as in the Eocene Little Mesa caddisfly bioherms (Leggitt and Cushman, 2001). In places discrete or fragmented cases occur (Fig. 5H). The caddisfly cases are generally cylindrical to subconical in external shape and are open at both ends. They are circular in the transverse section and subparallel to U-shaped in the longitudinal section. They usually show ellipsoidal shapes in the outcrop exposure and thin section. The cases are 10 to 20 mm long and 2 to 4 mm in diameter.

The cadddis cases are built by principally detrital particles. The particles are usually elongate fine-grained sands. They are oriented subparallelly along the case walls and are connected at intervals of 0.02 to 0.1 mm (Fig. 6A,B). They consist of limemudstone clasts, quartz and feldspar grains, and some wood fragments. It is characteristic that ooid particles are very rarely observed as the case-building particles in spite of the common presence of ooids in surrounding sediments. The ooids in surrounding deposits are usually coarse-grained sand in size (Fig. 6C). The siliciclastic particles are partially replaced by calcite. In general the cases are coated by two types of layers. One is inner micrite laminae and the other is outer micobial laminae (Fig. 6B,D,E). The inner micrite laminae are more or less than 0.05 mm thick interiorly and are 0.2 to 0.5 mm thick exteriorly. The microbial encrustation usually formed on the outside of the cases and the interior encrustation is limited (Fig. 6D,E). The discrete and fragmented cases are also coated by micrite and microbial laminae (Fig. 6F,G). However, some of fragmented ones have no microbial coating (Fig. 6H). Inside and outside the cases, ooids, peloids, and stromatolite fragments are filled and these grains are cemented with granular mosaic calcite (Fig. 6).

Pelletal and fenestral fabrics characteristic of blue-green algae (Scholle, 1978) are common in the encrusting stromatolites on the caddisfly cases (Fig. 7A–C). The outermost stromatolites have usually

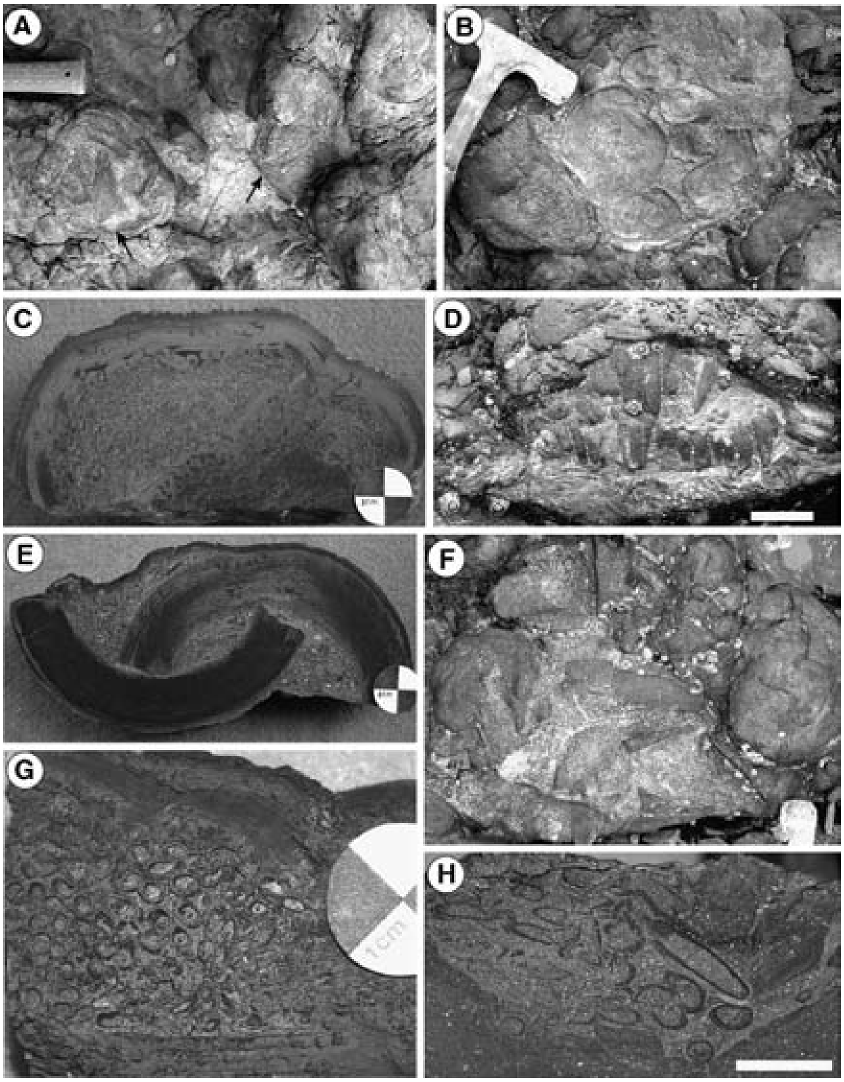
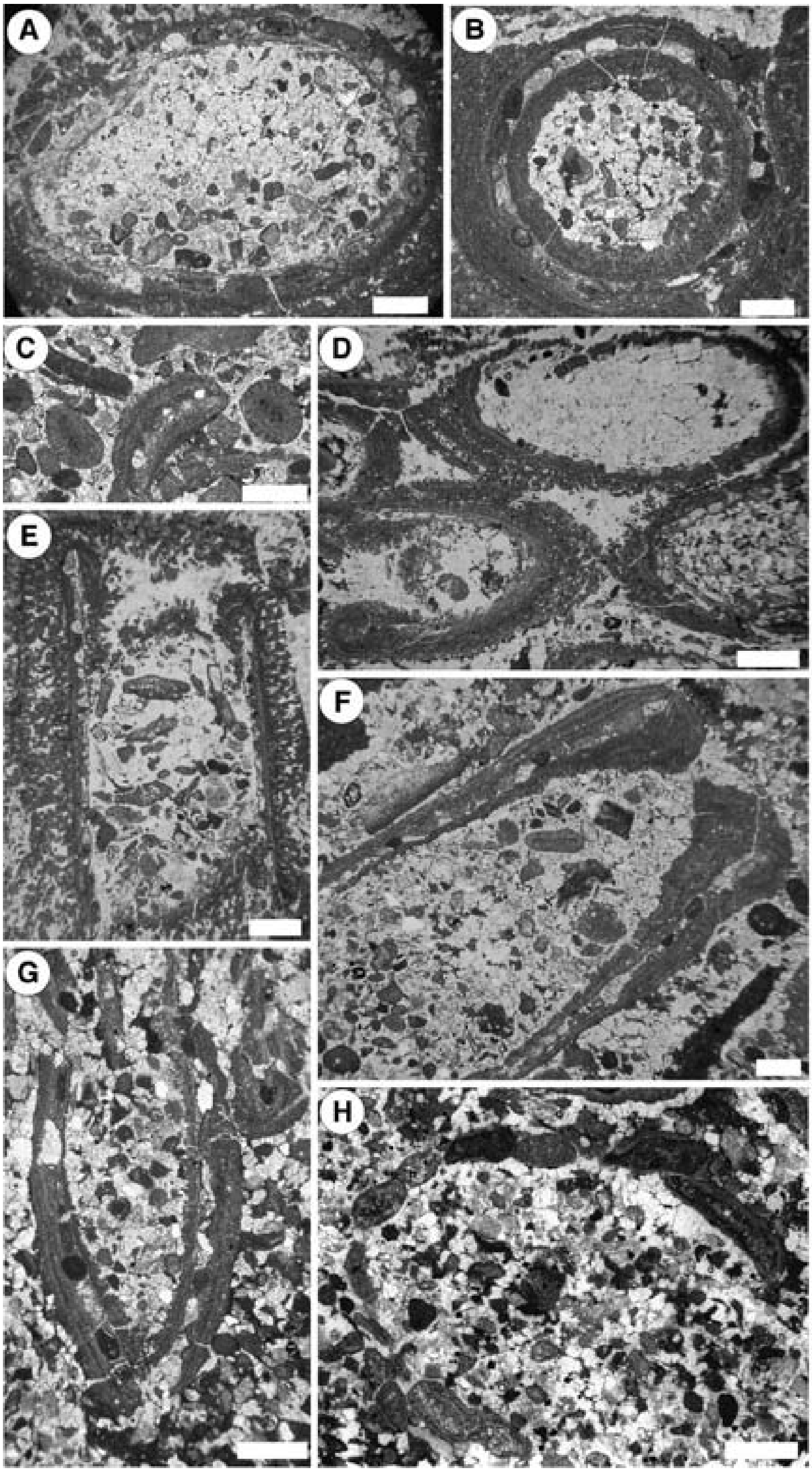


Fig. 5. Occurrence of caddisfly cases in Jahyeri microbial-caddisfly bioherm at site 1. (A) Planar sections of stromatolite columns (arrows) with cores of colonial caddisfly cases. (B) Planar section of larger stromatolite column bounding several small stromatolite columns with cores of colonial caddis cases. (C) Cross section of stromatolite column showing cores of colonial caddis cases on stromatolite fragment. Etched slab. (D) Three successive layers of colonial caddis cases forming terraces within one larger stromatolite column. (E) Fragmented and rebounded stromatolite columns. Etched slab. (F) Planar sections of regular arrays of parallel, subvertically aligned caddis cases. Scale bars are 2 cm. (G) Cross section of parallel, subhorizontally aligned cases. Scale bars are 2 cm. (H) Randomly distributed discrete cases. Scale bars are 1 cm.

microdigitate forms (Fig. 3D). Very thin calcite shells are preserved within the stromatolite laminae (Fig. 7D,E). They have symmetrical shapes in the cross section and are more or less than 2 mm in diameter. Their insides are filled with sparite. The caddisfly cases and encrusting stromatolites were

Fig. 6. Thin-section photomicrographs of caddisfly cases in Jahyeri microbial-caddisfly bioherm at site 1. Scale bars are 0.5 mm except one (1 mm) in (D). (A, B) Transverse sections of microbially coated cases showing subpararell orientation of elongate fine-grained sands along the case walls. (C) Coarse-grained ooids in the case-bearing deposits. Fragment of microbially coated caddis case is associated. (D, E) Colonial cases coated by inner micrite laminae and outer micobial laminae. The microbial encrustation inside the cases are limited. Discrete case (F) and fragmented case (G) also coated by micrite and microbial laminae. (H) Fragmented case without microbial coating.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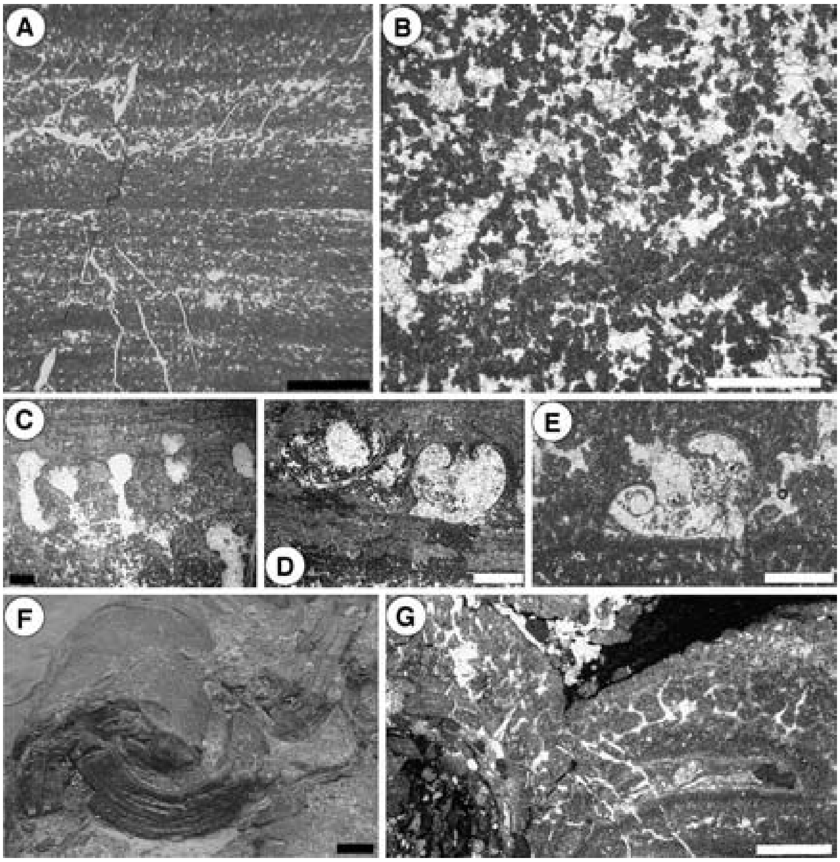

Fig. 7. Stromatolite encrusting colonial caddisfly cases in Jahyeri microbial-caddisfly bioherm at site 1. Scale bars are 0.5 mm (B, D,E,G), 1 mm (C), 2 mm (A) and 2 cm (F). (A) Pelletal and fenestral fabrics of microbial lamination. (B) Close view of pelletal and clotted fabrics. (C) Subvertical large fenestrae preserved in the microbial laminae. (D, E) Very thin calcite shells with nearly symmetrical shapes presumed to be exuviae of caddisfly larvae. (F) Penecontemporaneously fractured stromatolite. (G) Circumgranular cracks in stromatolite laminae.

commonly cracked and fractured penecontemporaneously (Fig. 7F). Fragments of these microbial-caddisfly bioherms occur above the bioherms. Some of the cortices on the stromatolite fragments within the bioherms are spalled off and recemented. Peloidal fabric by grainification (Read, 1974) and circumgranular cracks (Fig. 7G) and bladed calcite cement (Dewet et al., 1998), which are indicative of pedogenic origin, are present in the stromatolite laminae. The development of the microbial-caddisfly bioherms at site is summarized in Fig. 8.

The carbon and oxygen stable isotope analyses were conducted for calcite associated with the caddisfly cases (Fig. 9) by conventional techniques at Korea Basic Science Institute (Table 1). All of the samples have strongly negative values of δ^{18}O (less than -14) and δ^{13}C values around zero.

4.2. Site 2

Compared with the aggregated occurrence of bioherms at site 1, the caddisfly bioherm at site 2 occurs as an isolated small dome with a diameter of 25 cm and a height of 10 cm. The bioherm mostly consists of caddisfly cases (Fig. 10A), and stromatolite encrustation on the caddisfly bioherm is very thin (1 cm thick) and discontinuous (Fig. 10B) compared with the thick development of stromato-

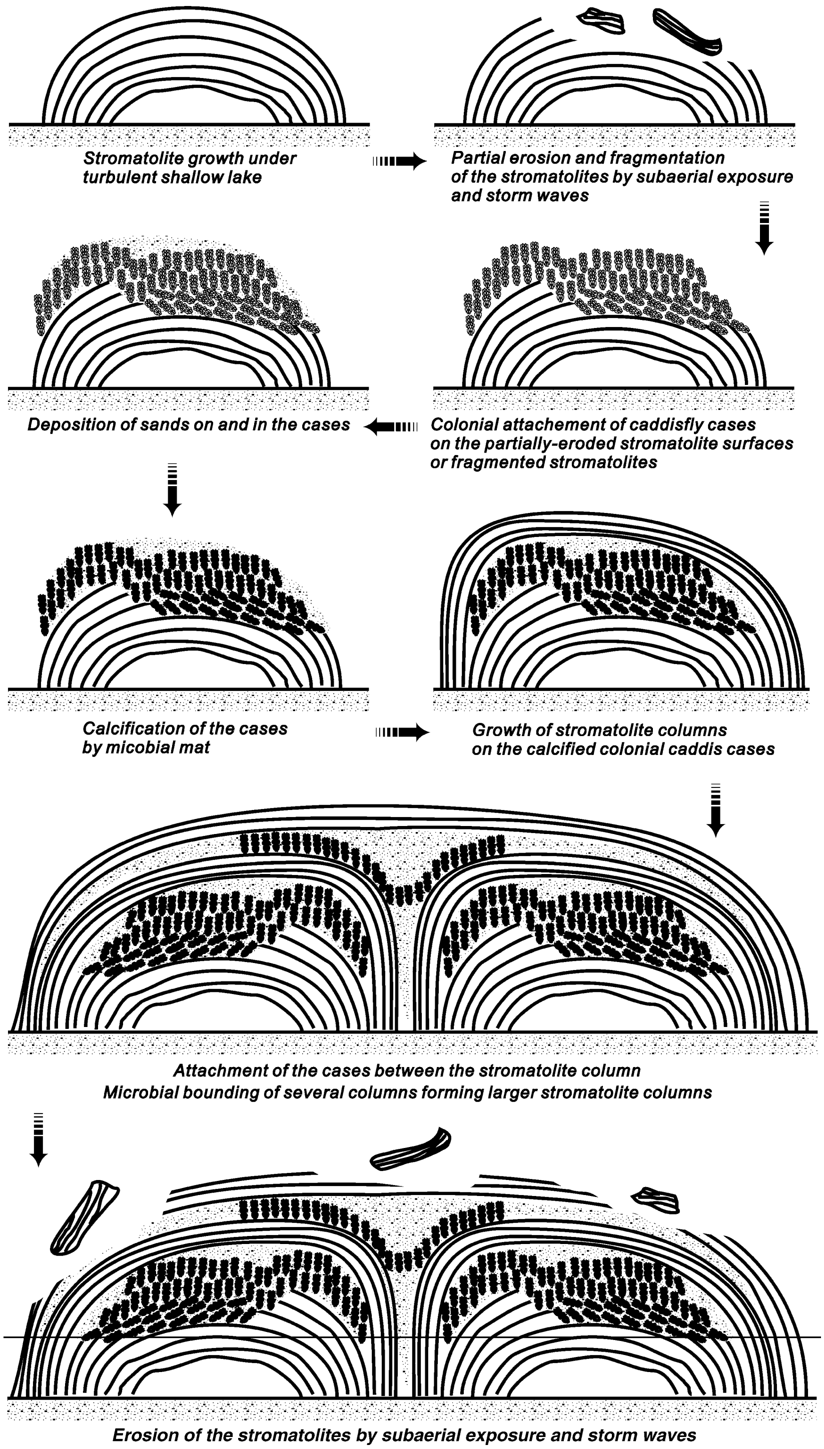

Fig. 8. Schematic diagram of the Jahyeri microbial-caddisfly bioherm development at site 1.

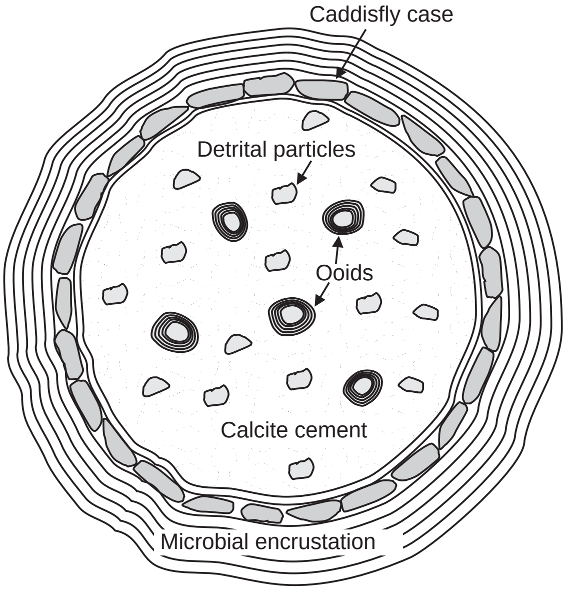

Fig. 9. Schematic diagram of microbially coated caddis case showing where the calcite samples in Table 1 were collected for carbon and oxygen stable isotope analyses.

lites in the caddisfly bioherms at site 1. The colonial caddisfly cases are built in the deposits consisting of medium-grained subarkosic sandstone and oolitic grainstone to wackstone. The sand grains are 0.2 to 0.8 mm in size and composed of quartz and feldspar grains, rock fragments, ooids, petrified or carbonized wood fragments, and fragments of green algae.

The caddisfly cases are also arranged with their long axes parallel to each other as in the bioherms at site 1. The long-axis orientations are subvertical in the lower part and subhorizontal in the upper part (Fig. 10A). The caddisfly cases are cylindrical and gradually tapering in external shape and are open at both ends as in the cases at site 1. They are circular in the transverse section (Fig. 10C–F) and subparallel in the longitudinal section. The cases are 20 mm long and 4 mm in diameter.

Table 1
Stable isotope values for calcites of the Jahyeri microbial-caddisfly bioherms

Sample	$\delta^{13}C_{PDB}$ (‰)	$\delta^{18}O_{PDB}$ (‰)	Remarks
JH-WT	−0.3	−14.3	ooid
JH-WT(1)	2.5	−14.5	microbial encrustation
JH-WT(2)	−0.8	−14.6	calcite cement
JH-8(1)	0	−17.3	microbial encrustation
JH-8(2)	0.1	−17.3	microbial encrustation
JH-8(3)	−0.2	−15.4	calcite cement
JH-8(4)	1.3	−17.3	microbial encrustation
JH-8(5)	0.7	−17.5	microbial encrustation
JH-8(6)	0.5	−16.3	microbial encrustation
JH-8-2	0.3	−16.7	ooid

The cadddis cases are also built by platy detrital particles. The particles are usually elongate and oriented subpararelly along the cases (Fig. 10E–G). They are closely connected like chains in transverse section and have some intervals of 0.1 to 0.2 mm in the longitudinal section. The particles are rock fragments, carbonized wood fragments and ooids, and are relatively larger (0.6 to 1 mm) than the sands in surrounding deposits. It is characteristic that the particles are generally oligomictic for each case (Fig. 10G). The cases are coated by thin calcite laminae (0. 1 mm thick) consisting of microsparite interiorly and exteriorly (Fig. 10H).

The matrix and cement of embedded deposits are generally calcareous. Calcite aureoles, crystallia and circumgranular cracks (Fig. 10I) indicative of pedogenesis (Freytet and Plaziat, 1982; Esteban and Klappa, 1983; Retallack, 1990) are observed. Laminated calcite like flowstone is present. Blue-green algal mats comparable to *Chlorellopsis coloniata* (Scholle, 1978) encrusted the caddisfly bioherm and

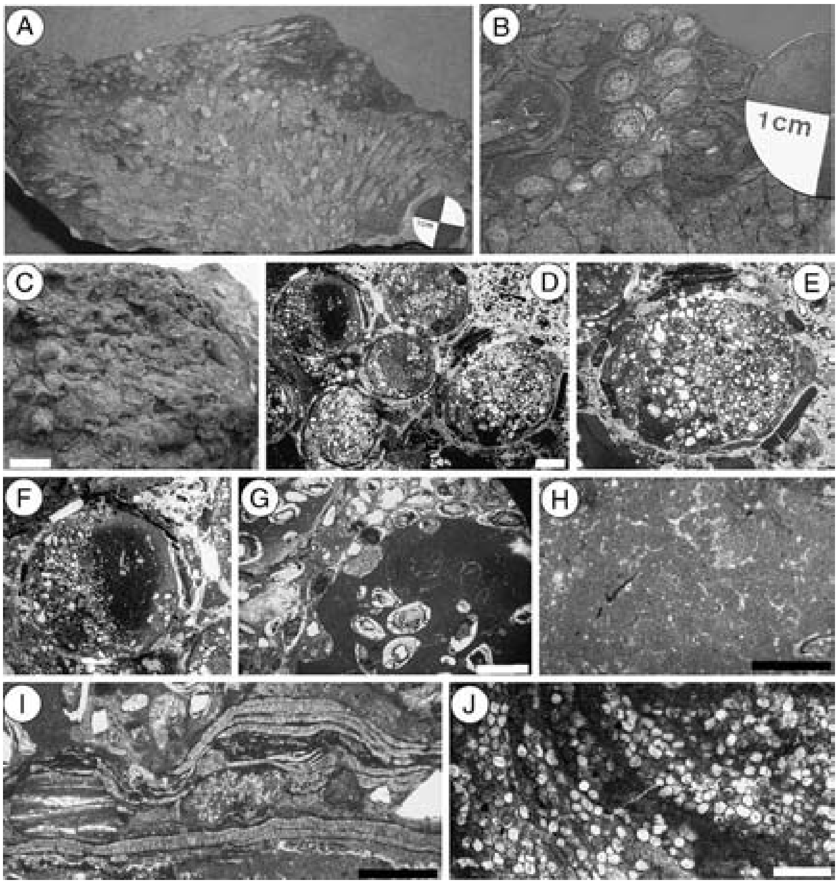

Fig. 10. Occurrence of Jahyeri microbial-caddisfly bioherm at site 2. (D) to (J) are thin-section photomicrographs. Scale bars are 0.5 mm (G, H, I), 1 mm (D), and 1 cm (C). (A) Cross section of caddisfly bioherm. Colonial caddis cases are subvertically aligned in regular arrays in the lower part, and subhorizontally aligned in the upper part. (B) Close view of upper-right part of (A) showing very thin and discontinuous microbial encrustation. (C) Oblique view of the bioherm showing circular opening of colonial cases. (D) Transverse section of cases showing subpararell orientation of elongate fine-grained sands along the case walls. (E) Close view of the case in right part of (D). (F) Close view of the case in upper-left part of (D). (G) Oligomictic composition of case-building particles. (H) Interior and exterior coating of case by thin calcite laminae consisting of microsparite. (I) Circumgranular cracks in case-filling micrite. (J) Blue-green algal mats compared to *Chlorellopsis coloniata* encrusted the caddis.

inside the cases (Fig. 10J), and remains of gastropod and ostracod are present in the bioherm. The cases and encrusting algal mats are partially cracked and fractured penecomtemporaneously.

5. Discussion

The common presence of polygonal desiccation cracks and small-scale wave ripples indicate that the depositional environment of caddisfly bioherm-bearing deposits at Jahyeri is a marginal lake. The intercalation of channel and splay deposits indicates that fluvial process was intermittently activated in the marginal lake. The bioherm development on and within oolitic sandstone suggests that the bioherms formed in shallow and turbulent water. The intraformational clast-bearing deposits above the bioherms suggest that storm flooding took place. The depositional condition of Jahyeri caddisfly bioherms is thus correspondent with the wave-washed and well-oxygenated biotope of modern lentic (lakes and ponds) Trichoptera (Mackay and Wiggins, 1979; Wiggins, 1998).

The association of stromatolites in the bioherms together with the occurrence on oolitic deposits suggests that the water was slightly saline (Lees, 1975). However, no marine fossils have been observed. High negative $\delta^{18}O$ values also suggest non-marine condition, although the depletion of $\delta^{18}O$ was affected by burial diagenesis (Tandon and Andrews, 2000). Penecomtemporaneous fractures and brecciation of the bioherms indicate that they suffered from subaerial exposure resulting from a retreat of the lake shore due to drought. The presence of calcareous pedogenic features supports the idea that the bioherms experienced long exposure before burial.

Jahyeri caddisfly bioherms are very similar in morphology and physical environment (shallow turbulent water) to modern worm reefs built by sabellarid worms. Sabellarid worms construct extensive wave-resistant reefs, by forming large colonies of agglutinated worm tubes (a few cm long and a few mm in diameter), on beaches to intertidal zones along tropical to subtropical coasts (Kirtley, 1992). The fossil worms building tubes of sand grains like the agglutinated worm tubes found in this study can be compared to Hermellidae (Carboniferous to Recent) and Sabellidae (Cretaceous to Recent) (Howell, 1962) occurring exclusively in marine deposits. The Jahyeri bioherms, however, are present in lacustrine deposits, suggesting that they are not agglutinated worm reefs.

Except for bioherm size, the Jahyeri microbial-caddisfly bioherms are compared to those of the Little Mesa bioherms in Eocene Green River Formation of USA (Leggitt and Cushman, 2001) in occurrence. The cylindrical shape, construction by sand particles, opening at both ends, and arrangement in regular arrays of Jahyeri caddisfly cases are similar to those of the Little Mesa bioherms. The symmetry of Jahyeri cases in cross section indicates that they are also portable cases like the Little Mesa cases. The size of Jahyeri cases is slightly larger than that of the Little Mesa cases. The Little Mesa caddisfly cases were assigned to those of the families Limnephilidae or Leptoceridae (Leggitt and Cushman, 2001). Limnephilidae is known from the Eocene and Leptoceridae is known from the Early Cretaceous (Ivanov and Sukatsheva, 2002).

Of the 20 modern caddisfly families in Korea, 11 families are tube-case makers. Of these tube-case makers (Yun, 1988), 5 families including Phryganeidae, Brachycentridae, Lepidostomatidae, Calamoceratidae, and Leptoceridae are known to be from the Early Cretaceous (Ivanov and Sukatsheva, 2002). Of these 5 families, only 2 families, viz., Phryganeidae and Leptoceridae have lentic biotope (Mackay and Wiggins, 1979; Wiggins, 1998). The larval cases of Phryganeidae are generally larger than 20 mm in size and are constructed by wood fragments which are generally overlapped, whereas the larval cases of Leptoceridae are smaller than 20 mm in size and are constructed by sand particles and some wood fragments which are generally not shingled (Yun, 1988). By comparing the two families in size, shape, and composition and construction way of case-building particles, it seems likely that the Jahyeri caddisfly cases can be tentatively attributed to the family Leptoceridae. However, fossil caddisfly cases of the Early Cretaceous leptocerid larvae collected in Siberia were built by pellets, in contrast to most fossil caddisfly cases in the Early Cretaceous being composed of sand particles (Ivanov and Sukatsheva, 2002). The Jahyeri caddisfly cases may be built by species other than the 'leptocerid' larvae from Siberia. The differences in case size and size and composition of construction particles between the sites 1 and 2 at Jahyeri suggest that at least two species might have inhabited the Jahyeri Lake.

Jahyeri microbial-caddisfly bioherms have common features with modern and Tertiary microbial-caddisfly bioherms in that the colonial caddisfly cases constructed bioherms in cooperation with a benthic microbial mat (Drysdale, 1999; Leggitt and Cushman, 2001). The caddis cases and microbial mat acted each other as stable substrates for calcification. Although the microbial mats intervene between the colonial caddisfly case layers in the Jahyeri bioherms, the development of microbial-caddisfly couplets is relatively poor in the Jahyeri bioherms compared with the well-development of alternating layers of caddisfly cases and microbial mats. The poor development of intervening microbial mats is deemed to have been attributed to slow development of the mats due to hostile condition.

The Jahyeri microbial-caddisfly bioherms are all that have been discovered throughout the Jinju Formation, and the Jahyeri bioherms are very small compared with the tall growth of the Little Mesa bioherms. It is interpreted that such limited growth and occurrence of microbial-caddisfly bioherms in the Jinju Formation resulted from the predominance of clastic deposition in the Jinju Lake. The occurrence of Jahyeri microbial-caddisfly bioherms is thus considered to be related with the development of a drought stage which resulted in limited supply of clastic sediments into the Jahyeri Lake. The common development of pedogenic features in the Jahyeri bioherms supports the development of a drought stage.

Although fossil caddisfly cases are abundant in the Early Cretaceous, microbial-caddisfly bioherms have never been documented in the Cretaceous. As previously mentioned, the Early Cretaceous caddisflies have all been found in Transbikalia and Mongolia (Ivanov and Sukatsheva, 2002). The Jahyeri microbial-caddisfly bioherms thus suggest that the evolution of caddisflies in the Early Cretaceous was made mainly in the eastern region of Asia. The Jahyeri microbial-caddisfly bioherms may be the oldest occurrence of microbial-caddisfly bioherms in the geological records. The similarity between the Jahyeri microbial-caddisfly bioherms and those from the Tertiary and modern deposits suggests that caddisflies played an important role in constructing carbonate bioherms in non-marine environments and the physical environments of microbial-caddisfly symbiosis has changed little throughout geologic time and space. It thus indicates that the microbial-caddisfly bioherms can be a useful record to interpret paleohydrological condition including turbulent and well-oxygenated environment.

6. Conclusions

1. Fossil microbial-caddisfly bioherms have been discovered in the Early Cretaceous lacustrine deposits (Jinju Formation) at Jahyeri, Korea. This finding is the first report of microbial-caddisfly bioherms in Asia and represents the oldest occurrence of microbial-caddisfly bioherms in the geological records.
2. The depositional condition of Jahyeri caddisfly bioherms is correspondent with the wave-washed and well-oxygenated biotope of modern lentic Trichoptera.
3. By comparing the habitat, size and shape of cases, composition of case-building particles, and case construction way, it seems likely that the Jahyeri caddisfly cases can be tentatively attributed to the family Leptoceridae.
4. The limited growth and occurrence of microbial-caddisfly bioherms in the Jinju Formation resulted from the predominance of clastic deposition in the Jinju Lake. The occurrence of Jahyeri microbial-caddisfly bioherms may reflect the development of a drought stage which resulted in a limited supply of clastic sediments into the Jahyeri Lake.
5. The similarity between the Jahyeri microbial-caddisfly bioherms and those from the Tertiary and modern deposits suggests that the physical environments of microbial-caddisfly symbiosis has changed little throughout the geologic time and space, and thus indicates that the microbial-caddisfly bioherms can be used to interpret paleohydrological condition.

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