Microscopic microbialite textures and their components in a Lower Devonian lagoonal facies of the Fukuji Formation, Gifu Prefecture, central Japan

Natsuko ADACHI, Yoichi EZAKI

ADACHI, N. & EZAKI, Y., 2007: Microscopic microbialite textures and their components in a Lower Devonian lagoonal facies of the Fukuji Formation, Gifu Prefecture, central Japan. – In: HUBMANN, B. & PILLER, W. E. (Eds.): Fossil Corals and Sponges. Proceedings of the 9th International Symposium on Fossil Cnidaria and Porifera. – Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 17: 215–229, 2 Figs., 2 Pls., Wien.

Abstract: Varied microbialite textures together with skeletal metazoans such as tabulate and rugose corals and stromatoporoids are present in the Lower Devonian lagoonal Fukuji Formation, Gifu Prefecture, central Japan. Stromatolitic, thrombolitic, and leiolitic textures that have formed around the skeletons comprise three main components: peloids, micrites, and calcimicrobes. The calcimicrobe *Girvanella* is ubiquitous and is closely associated with the formation of varied microbialite (stromatolitic, thrombolitic, and leiolitic) textures as accumulations, partial aggregations, and random distributions. Peloids and micrites also exhibit varied microbialite textures by manners of assemblage similar to those in *Girvanella*. *Girvanella* itself in some cases gives rise to peloids and micrites. In contrast, *Rothpletzella* and *Renalcis* relate only to the formation of particular microbialite textures such as stromatolitic and thrombolitic textures, respectively. Microbialite textures have not yet been fully examined in Devonian lagoonal environments. However, it is emphasized that *Girvanella* was comparatively abundant there and played an important role in the genesis of varied microbialite textures and their components, as seen in the lagoonal Fukuji Formation.

Key words: Microbialite textures, components, *Girvanella*, lagoonal environment, Lower Devonian, Japan

Contents

Department of Geosciences, Osaka City University, Sugimoto 3-3-138, Sumiyoshi-ku, Osaka 558-8585, Japan, e-mail: natsuko@sci.osaka-cu.ac.jp

1. INTRODUCTION

The Devonian period is identified as one of the most remarkable reef-building episodes in the Phanerozoic (e.g. COPPER, 2002). Skeletal organisms such as stromatoporoids and corals, and increasingly calcimicrobes, are the major frame-builders (WEBB, 1996). The calcimicrobes *Renalcis*, *Epiphyton*, *Rothpletzella*, and *Wetheredella* are especially significant in Devonian reefs (e.g. CHUVASHOV & RIDING, 1984). Microbialites such as thrombolites and stromatolites attained sufficient relief to form some shallow reefs (CLOUGH & BLODGETT, 1989). The features of calcimicrobes and microbialites in Devonian reefal limestones have been discussed (e.g. MOUNTJOY & RIDING, 1981; WOOD, 2000). Calcimicrobes such as *Girvanella*, *Rothpletzella*, *Renalcis*, *Wetheredella*, and *Epiphyton* are also present in the Devonian lagoons (e.g. TSIEN, 1979). *Girvanella* is comparatively abundant there and it forms nodules and laminated crusts on other constituents (e.g. WRAY, 1977; TSIEN, 1979). However, in Devonian lagoonal environments, microbialite features in particular have not yet been fully examined.

Microfacies analysis and constituents of the skeletal components of the Lower Devonian (Lochkovian to Emsian) Fukuji Formation, Gifu Prefecture, central Japan, suggest that these limestones were formed in a lagoonal environment. Calcimicrobes and microbialites occur together with tabulate and rugose corals and stromatoporoids. Microbialites are ubiquitous and microbes largely contribute to the limestone formation (EZAKI & ADACHI, 2000).

The purpose of this study is to elucidate the relationships of microbialite textures and their components in order to get a better understanding of the microbialite features in the Lower Devonian lagoonal Fukuji Formation. We first describe features of the main calcimicrobes (*Girvanella*, *Rothpletzella*, *Wetheredella*, and *Renalcis*) and the characteristic limestones. We then describe the features of microbialite (stromatolitic, thrombolitic, and leiolitic) textures, before discussing the relationships between microbialite textures and their components.

2. GEOLOGICAL SETTING

Devonian strata are sparse in the Japanese Islands and are restricted to the Hida "Gaien," Southern Kitakami, Abukuma, and Kurosegawa terranes. However, the Fukuji Formation (KAMEI, 1952) that we have studied belongs to the Hida "Gaien" Terrane, and is distrib-

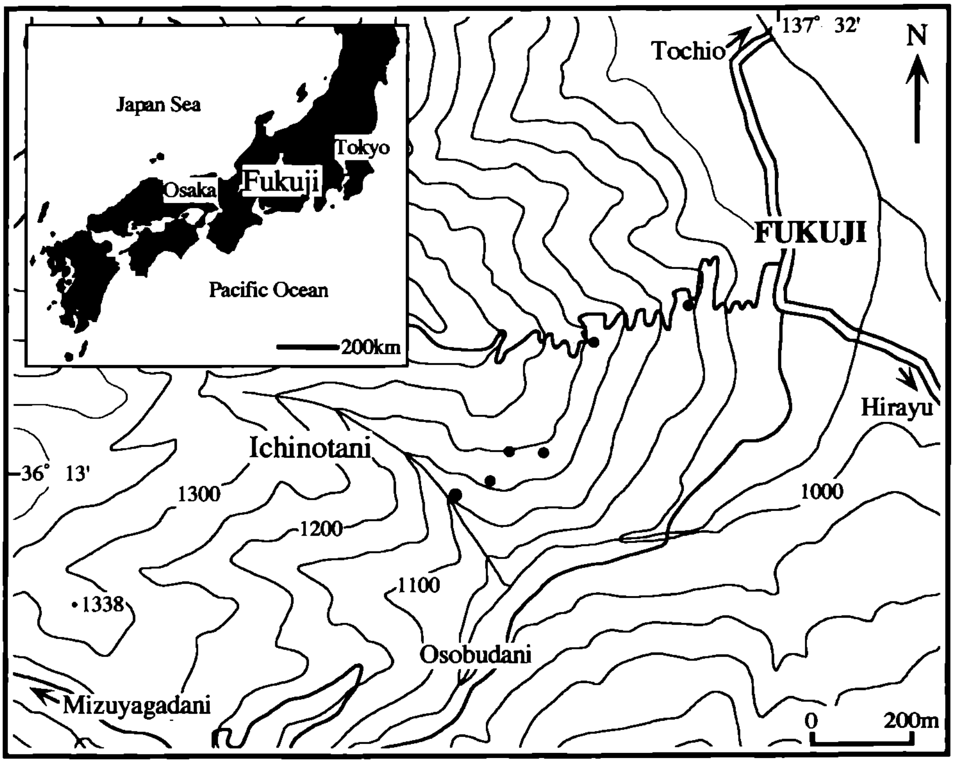


Fig. 1: Index map showing the study area at Fukuji in Gifu Prefecture, central Japan, and sample localities (black dots).

uted in the Fukuji area of Gifu Prefecture, central Japan (Fig. 1). It yields abundant and well-preserved fossils such as tabulate and rugose corals and stromatoporoids. Palaeontological studies have been done by KAMEI (1955), KOBAYASHI & HAMADA (1977), OHNO (1977), and KATO et al. (1980). With a total thickness of 250 m, this formation is characterized by fossiliferous, bedded limestones and intercalated acidic tuffs, and has been divided into three members and further subdivided into eleven beds (beds 1 to 11) by KAMEI (1955). Its age ranges from Lochkovian to Emsian (Early Devonian) based on corals and conodonts (KATO et al., 1980; KUWANO, 1987), and it is in fault contact with the overlying Ichinotani Formation of Carboniferous age. The macroscopic features of the skeletal limestones in each bed are as follows, in ascending order: Bed 1 is characterized by black, bedded limestone, and Bed 6 is marked by greenish acidic tuff that nevertheless yields tabulate corals. Bed 7 consists of grey to dark grey limestone. Beds 8 and 10 are mainly composed of black, muddy limestone, and Bed 11 consists of grey limestone. The other beds are poor in macrofossils and in some cases include fine terrigenous particles.

3. MATERIALS AND METHODS

Most specimens used in this study were collected by Professor T. Kamei in the 1940s and 1950s, with reference to the stratigraphic scheme for the Fukuji Formation proposed by KAMEI (1952, 1955) that has been generally accepted by later workers (e.g. NIIKAWA, 1980; KUWANO, 1987). Large thin sections (7.5 x 10 cm) and small thin sections (5 x 7.5 cm) were prepared for microfacies analysis. Many other thin sections, now stored at the Department of Earth and Planetary Sciences, Hokkaido University, and the Department of Geological Sciences, Shinshu University, also were made available to us. Beds 1, 7, and 11, in which occur abundant tabulate and rugose corals, stromatoporoids, calcimicrobes, and microbialites were mainly studied based on about 300 thin sections. The relative abundance of skeletal components and calcimicrobes has been established from these thin sections.

4. MAIN CALCIMICROBES

The calcimicrobes *Girvanella*, *Rothpletzella*, *Wetheredella*, and *Renalcis* are present in the study materials. *Girvanella* is common in limestone lithofacies, where it consists of nonbranching and micrite-walled filaments. *Girvanella* is differentiated, based on its growth habitat, into tangled and parallel adherent types. The tangled type further includes two types: tightly intertwined filaments (Pl. 1 A, B) and isolated filaments, based on the density of filaments. The external diameter of filaments is 5–20 μm. This type of *Girvanella* is present in crusts that formed around skeletal components and matrices. It is also related to the destruction of bioclasts by bioerosion. The parallel adherent type is only present in matrices. The external diameter of the filaments is 10–15 μm.

Rothpletzella is common in part. It is recognized as multi-layers composed of juxtaposed filaments (Pl. 1 C). In longitudinal section, the branching pattern is noticeably fan-like in shape. The diameter of the filaments ranges from 20 to 50 μm. *Rothpletzella* often co-occurs with *Wetheredella* and *Girvanella* (Pl. 1 D), and it can be seen penetrating the surface of skeletal components in some materials.

Wetheredella is common in part. It is generally subcircular and rarely is spherical or vermiform in shape (Pl. 1 D). It ranges from 150 to 650 μm in width and 50–250 μm in height. *Wetheredella* consists of a thinner micritic outer wall (2–3 μm in width), underlain by a fibrous calcite layer (15–50 μm in width) in which the inner parts are filled in with mosaic calcites.

Renalcis is partly clustered but is not common. It is aggregated of hollow, inflated chambers, with thick, micritic walls, and is 100–300 μm in diameter (Pl. 1 E). The micritic wall is 40–80 μm thick. *Izhella* (the *Renalcis* group, *sensu* RIDING, 1991), characterized by v-shaped clefts on the inner sides of the thick, micritic walls, is also found together with *Renalcis*.

5. DESCRIPTION OF CHARACTERISTIC LIMESTONES

5.1. Stromatoporoid-coral boundstones

This type of rocks is recognized in extremely dark-grey limestones associated with beds 1 and 7. *Amphipora* is locally abundant and well-preserved. Stromatoporoids occupy 8–80% (average 35%) and tabulate and rugose corals occupy 1–12% (average 6%), whereas brachiopods, gastropods, and ostracodes occupy on average 2%, and crinoids occupy on average less than 1%. The calcimicrobe *Girvanella* occupies 1–2%, whereas *Rothpletzella* and *Wetheredella* each occupy ca. 1%.

Tabulate corals such as *Favosites* and solitary rugose corals such as *Tryplasma* are sometimes entirely surrounded by stromatoporoids, and these envelopes are 1–2 cm thick. The stromatoporoid *Clathrodictyon* has a low, domal growth form, and thin veneers of micrites (100–600 μm thick) which include *Girvanella*, and the rugose and tabulate corals are occasionally intercalated with stromatoporoids. The stick-like stromatoporoid *Amphipora* is occasionally surrounded by a thick crust of peloids and micrites (maximum 1.5 mm thick), where tangled *Girvanella* occurs sporadically or densely (Pl. 1 G, H). Surfaces of tabulate and rugose corals are directly surrounded by *Rothpletzella*. Spherical to ovoid, silt- and sand-size peloids, and tangled and parallel adherent *Girvanella* are scattered in the matrix.

5.2. Bioclastic floatstones/wackestones

This type of rocks is recognized in beds 1, 7, and 11 and is particularly abundant in Bed 7, which has a grey to dark colour. Tabulate and rugose corals occupy 2–50% (average 20%) of the areas in thin sections, whereas crinoids, brachiopods, and ostracodes occupy ca. 10% in total. *Girvanella* occupies a maximum of 6% (average 3%), *Rothpletzella* occupies a maximum of 7% (average 1%), whereas *Wetheredella* occupies a maximum of 6% (average below 1%). *Renalcis* is not common and occupies less than 1%.

Tabulate and rugose corals such as *Cystiphylloides*, *Tryplasma*, and *Thamnopora*, crinoids, and brachiopods are micritized along their periphery and are further covered by peloids and calcimicrobes including *Girvanella*, *Rothpletzella*, and *Wetheredella*. Skeletal components such as tabulate and rugose corals are occasionally directly covered by calcimicrobes, peloids, and micrites (Pl. 1 C, F). Crusts of tangled tubes of *Girvanella* alternate with layers of *Rothpletzella*, and are in part intergrown with *Wetheredella* and *Rothpletzella*. A fuzzy, laminated accumulation of peloids (20–60 μm in diameter) encrusts the tabulate coral *Thamnopora* and crinoids (Pl. 2 A, B). These encrustations include tangled *Girvanella*. These peloidal, micritic, and calcimicrobial envelopes surrounding skeletal components exhibit oncoidal, and tabulate to domal growth forms, or develop in one direction to form a columnar growth form (Pl. 2 A).

The multi-layered filaments of *Rothpletzella* also rarely directly encrust sediments and are further covered by tangled tubes of *Girvanella* and *Wetheredella* (Pl. 1 A). Cavity spaces formed by the calices of the tabulate coral *Favosites* are filled in with peloids (Pl. 2 C). These peloids are small (20–60 µm in diameter), well-sorted, and partly gathered to exhibit a clotted fabric. *Renalcis* is scattered and/or partly clustered in the matrix of floatstones/wackestones, where silt- and sand-size peloids as well as parallel adherent and/or tangled *Girvanella* are present (Pl. 2 D).

5.3. Bioclastic packstones/rudstones

Bioclastic packstones/rudstones are subdivided into two types: crinoid packstones/rudstones and coral-sponge packstones/rudstones.

Crinoid packstones/rudstones are characteristic of Bed 7. Crinoids are most abundant and occupy 13–40% (average 25%). Brachiopods occupy a maximum of 8% (average 3%), whereas corals, gastropods, and ostracodes are 1–3%, respectively. *Girvanella* occupies 1–8% (average 3%), whereas *Rothpletzella* and *Wetheredella* each occupy below 1%.

Crinoids and tabulate and rugose corals are micritized along their periphery and are covered by peloids, micrites, and calcimicrobes, including *Girvanella*, *Wetheredella*, and *Rothpletzella*. Within the peloidal and micritic envelopes, tangled *Girvanella* is sporadically or densely included. Their encrustations show spherical to ovoid shapes, occasionally forming domal to columnar growth forms. Oncoids with irregular laminae are formed around crinoids, the tabulate corals *Favosites* and *Thamnopora* and the stromatoporoid *Amphipora*. These envelopes (2–3 mm thick) consist of peloids, micrites, and calcimicrobes, where *Girvanella* is most abundant and is partly clustered with each other. Laminae are occasionally exhibited as accumulations of different sizes of *Girvanella* filaments and densities (Pl. 2 E, F). In micritic matrices of packstones/rudstones, silt- and sand-sized peloids, parallel adherent and tangled *Girvanella* are present.

Coral and sponge packstones/rudstones are mainly recognized in Bed 11. Corals occupy 3–21% (average 17%) and siliceous sponges occupy a maximum of 20% (average 8%) in thin sections. Crinoids, brachiopods, and ostracodes are all below 1% each. The calcimicrobe *Girvanella* is 2–4%, whereas *Rothpletzella* and *Wetheredella* occupy ca. 1%, respectively.

Siliceous sponges are selectively recrystallized, so that internal textures are obscure. Crinoids, siliceous sponges and tabulate and rugose corals are heavily bored by endolithic microbes and outlined by dark, micritic envelopes. Peripherally micritized cores are further surrounded by peloids, micrites, and calcimicrobes forming oncoids (Pl. 2 G, H). Oncoids are spherical to ovoid in shape and 3–8 mm in diameter. The envelopes, which are composed of peloids and micrites, at most 2 mm in thickness, occasionally include *Girvanella* and rarely *Rothpletzella*. *Wetheredella*, *Rothpletzella*, *Girvanella*, and combinations of them, directly encrust the surfaces of both the tabulate coral *Thamnopora* and rugose coral *Tryplasma*. Peloids (mainly silt-size) have filled in cavity spaces formed by brachiopod shells and calices of the tabulate coral *Favosites*. Fused networks of peloidal fabrics occasionally show clotted fabrics, in which bioclasts and calcimicrobes are scarcely recognized. Silt- and sand-size peloids, and tangled and parallel adherent *Girvanella* are scattered in matrices of packstones/rudstones.

6. MICROBIALITE TEXTURES

Three different microbialites are distinguished based on textures: stromatolitic (laminated), thrombolitic (clotted), and leiolitic (structureless). Oncoid is a growth form, such as domal or columnar, rather than a microbialite texture (e.g., LEINFELDER & SCHMID, 2000).

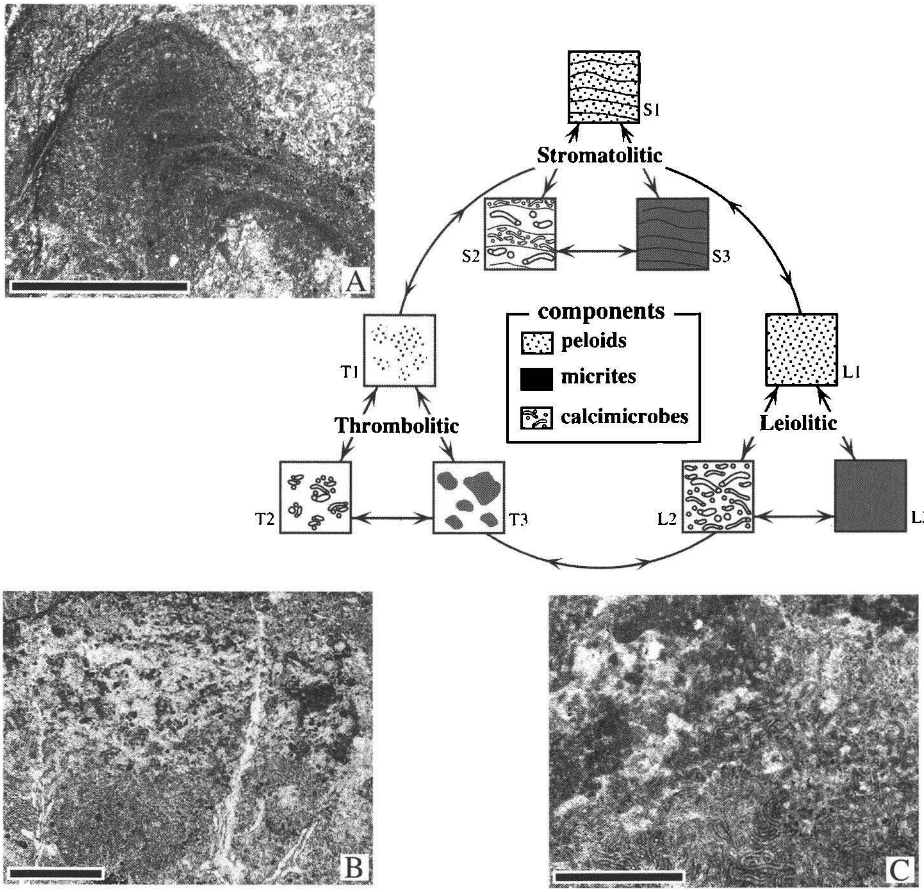


Fig. 2: Relationship between microbialite textures (stromatolitic, thrombolitic, and leiolitic) and their components (calcimicrobes, peloids, and micrites). Classification is based on KENNARD & JAMES (1986), DUPRAZ & STRASSER (1999), and LEINFELDER & SCHMID (2000). *Girvanella* is closely related to the formation of varied microbialite textures.

(A) Stromatolitic texture formed by accumulations of *Girvanella*. It corresponds to S2. Scale bar = 1 mm.

(B) Partial aggregations of *Girvanella* and peloids form thrombolitic textures. It corresponds to the intermediate stages between T2 and T3. Scale bar = 1 mm.

(C) Leiolitic textures formed by randomly distributed *Girvanella*. It corresponds to L2. Scale bar = 1 mm.

It is characterized by laminae and thus contains stromatolitic textures. The main components of microbialite textures are peloids, micrites, and calcimicrobes.

6.1. Stromatolitic textures

Stromatolitic textures are common in bioclastic limestones. Stromatolitic textures occur on skeletal components such as tabulate and rugose corals and crinoids, showing tabular to domal, columnar, and oncoidal growth forms with laminae at intervals of several micrometers to several tens of micrometers. Stromatolitic textures are formed by accumulations of peloids, micrites, and calcimicrobes (Fig. 2). Dense accumulations of peloids encrust skeletal components, occasionally showing stromatolitic textures (Pl. 2 B) where laminae are visible due to differences in density. Most of the peloids are silt-size and well-sorted. Micrites which encrust skeletal components also exhibit fuzzy laminae (Pl. 1 F). Tangled *Girvanella* are included in part within stromatolitic textures formed by peloids and micrites. Layers formed by *Girvanella* of two different diameters occasionally form a stromatolitic texture (Fig. 2 A, Pl. 2 E, F). Layers of *Girvanella* with small diameters (5 µm) show darker micritic layers, whereas layers of *Girvanella* with larger diameters (15–20 µm) show brighter layers where filaments are sparse and sparry calcite fills their interspaces (Pl. 2 F). *Rothpletzella* exhibits stromatolitic textures as accumulations of filaments (Pl. 1 C).

6.2. Thrombolitic textures

Thrombolitic textures are common in coral-stromatoporoid boundstones and bioclastic limestones. Thrombolitic textures are present around skeletal components such as corals, siliceous sponges, and stromatoporoids. Their encrustations, from several micrometers to 1 centimetre in thickness, exhibit tabular to domal or spherical growth forms where clots originated from micrites, peloids, and calcimicrobe *Girvanella* (Fig. 2). Each clot is several tens to several hundreds of micrometers in size. Tangled *Girvanella* are occasionally included within clots of peloids and micrites (Fig. 2 B, Pl. 1 G, H). *Renalcis* is not common, but its aggregations, scattered among skeletal components occasionally exhibit thrombolitic textures. Cavity spaces formed by shells of brachiopods and calices of the tabulate coral *Favosites* are filled in with peloids that are clustered to some degree to form clotted fabrics (Pl. 2 C). These peloids are small (20–60 µm) and well-sorted, occasionally exhibiting a geopetal texture within the cavities.

6.3. Leiolitic textures

Leiolitic textures occur irrespective of lithofacies. Densely distributed peloids cover skeletal components such as tabulate and rugose corals and crinoids where tangled *Girvanella* are included, and occasionally are further encrusted by *Rothpletzella* and *Wetheredella*. Surfaces of bioclasts such as crinoids are encrusted by dense micrites where tangled *Girvanella* are included, changing laterally into encrustations of dense

Girvanella. Tabulate and rugose corals are surrounded by thick encrustations of calcimicrobes (*Rothpletzella*, *Wetheredella*, and *Girvanella*) (Fig. 2 C). These encrustations show tabular to domal growth forms and do not exhibit characteristic textures.

7. DISCUSSION

Reefs formed by skeletal metazoans, calcimicrobes or synsedimentary cements are unknown from the Fukuji Formation, whereas benthic skeletal organisms characterized by slender stromatoporoids and tabulate corals are abundant. *Amphipora* (dendroid stromatoporoid) occurs at several horizons and is generally regarded as an indicator of very shallow water and a sheltered lagoonal environment (e.g. SOJA, 1988; POHLER, 1998).

Even in the lagoonal environments, microbialites, ranging from a few millimeters to several centimeters thick, are observed around skeletal components, showing tabular to domal, columnar, and spherical growth forms. Stromatolitic, thrombolitic, and leiolitic textures are formed of three principal components: peloids, micrites, and calcimicrobes (Fig. 2). Peloids and micrites are common components of ancient microbialites (e.g., DUPRAZ & STRASSER, 1999; LEINFELDER & SCHMID, 2000), whereas calcimicrobes such as *Rothpletzella* and *Renalcis* are characteristic of Middle Palaeozoic equivalents. Although the relative abundance of calcimicrobes is not high (average 4%) in the study material, *Girvanella* is ubiquitous and is closely related to the formation of a variety of microbialite (stromatolitic, thrombolitic, and leiolitic) textures. *Girvanella* exhibits stromatolitic textures by its accumulation of different sizes of filaments and densities (Fig. 2 A, Pl. 2 E, F). In addition, *Girvanella* is associated with thrombolitic textures by sporadically being tangled with each other and/or with leiolitic textures by randomly being distributed (Fig. 2). Accumulations, partial aggregations, and random distributions of peloids and micrites also exhibit stromatolitic, thrombolitic, and leiolitic textures, where *Girvanella* may be involved to some extent. The dark micritic envelops (leiolitic textures) around skeletal components also include *Girvanella* (Pl. 2 G, H). *Girvanella* is also associated with bioerosion (e.g. TSIEN, 1979; RIDING & SOJA, 1993).

Isolated filaments of *Girvanella* and peloids with vestiges of its filamentous morphology are also included in the peloid-rich microbialites. *Girvanella* is generally interpreted to be the calcified sheath of a variety of filamentous cyanobacteria (e.g. RIDING, 1977; DANIELLI, 1981). The genetic interrelationship between calcimicrobes (filamentous and coccoidal) and peloids has been discussed by TURNER et al. (2000) and ADACHI et al. (2004). The varied preservation of microbes hinges on whether calcification of the sheath was *syn-vivo* or *post-mortem*, or both, and on the extent of calcification. PRATT (1995, Fig. 62) also exhibited intergrading textures (*Girvanella*, thrombolites, and biomicrites) of filamentous cyanobacteria based on differences in filamentous calcification, degradation, and sedimentation. The presence of peloids, micrites, and *Girvanella* as main microbialite components might be interrelated. *Girvanella* may be preserved as *Girvanella*-only crusts in some cases, and within peloid- and micrite-dominated crusts in other cases.

On the other hand, *Rothpletzella* shows stromatolitic textures by having layered features (Pl. 1 C), and *Renalcis* occasionally exhibits thrombolitic textures. These calcimicrobes are thus concerned with the formation of particular microbialite textures, respectively.

In the geological record, peloids occur as irregular, dome-shaped coatings on bioclasts, or fill confined cavities. These fabrics are inferred to result from *in situ* growth products generally related to microbial activities (e.g. Reid, 1987; Sun & Wright, 1989). Peloid-dominated microbialite crusts around skeletal components, and peloidal fillings within cavity spaces, formed within the shells of brachiopods and the calices of tabulate corals, may in some cases have originated from microbial, especially bacterial, activity.

In the Lower Devonian lagoonal Fukuji Formation, calcimicrobes, peloids, and micrites are principal microbialite components. Some of the components in themselves are genetically interrelated with each other. Microbes such as bacteria almost undoubtedly contributed to the formation of microbialite textures. In particular, the calcimicrobe *Girvanella* was comparatively abundant in Devonian lagoons (e.g. Wray, 1977; Tsien, 1979) and inferred to have been intimately related to the formations of varied microbialites and their components, as in the lagoonal Fukuji Formation.

8. CONCLUSIONS

1. In the Lower Devonian lagoonal Fukuji Formation, three principal components (calcimicrobes, peloids, and micrites) produce microbialite (stromatolitic, thrombolitic, and leiolitic) textures.
2. *Girvanella* is closely related to microbialite textures, and its accumulations, partial aggregations, and random distributions lead to the production of stromatolitic, thrombolitic, and leiolitic textures. Peloids and micrites also exhibit varied microbialite textures, though growth manners are similar to those in *Girvanella*. *Girvanella* itself may be involved in the formation of peloids and micrites. *Rothpletzella* and *Renalcis* produce particular microbialite textures such as stromatolitic and thrombolitic textures, respectively.
3. *Girvanella* is comparatively abundant in Devonian lagoons, suggesting its great contribution to a variety of microbialite textures, as seen in the lagoonal Fukuji Formation.

Acknowledgements: We cordially thank Professor Emeritus T. Kamei (Kyoto University) and Professor Emeritus M. Kato (Hokkaido University) for providing us with numerous specimens and for their encouragement . We are grateful to Dr. D. Vachard (Lille University) for reviewing this paper. The authors thank Professor A. Yao (Osaka City University) for encouragement. This study was supported by grant no. 14540440 from the Scientific Research Fund of the Japan Society for the Promotion of Science.

References

Adachi, N., Ezaki, Y. & Liu, J., 2004: The fabrics and origins of peloids immediately after the end-Permian extinction, Guizhou Province, South China. – Sedimentary Geology, **2004** (164): 161–178, Amsterdam.

Copper, P., 2002: Silurian and Devonian Reefs: 80 Million years of global greenhouse between two ice ages. – In: Kiessling, W., Flügel, E. & Golonka, J. (Eds.): Phanerozoic reef patterns. – SEPM Special Publication, **72**: 181–238, Tulsa.

Chuvashov, B.J. & Riding, R., 1984: Principle floras of Paleozoic marine calcareous algae. – Palaeontology, **1984** (27): 487–500, London.

Clough, J.G. & Blodgett, R.B., 1989: Silurian-Devonian algal reef mound complex of Southwest Alaska. – In: Geldsetzer, H.H.L., James, N.P. & Tebbutt, G.E. (Eds.): Reefs, Canadian and adjacent areas. – Canadian Society of Petroleum Geologists Memoir, **13**: 404–407, Calgary, Alberta.

Danielli, H.M.C., 1981: The fossil alga *Girvanella* Nicholson & Etheridge. – British Museum (Natural History) Bulletin, Geology series, **1981** (35): 79–107, London.

Dupraz, C. & Strasser, A., 1999: Microbialite and microencrusterers in shallow coral bioherms (Middle to Late Oxfordian, Swiss Jura Mountains). – Facies, **1999** (40): 101–130, Erlangen.

Ezaki, Y. & Adachi, N., 2000: Calcimicrobes and microbialites from the Lower Devonian Fukuji Formation, Hida "Gaien" Terrane, Southwest Japan – The Journal of the Geological Society of Japan, **2000** (106): 901–904, Tokyo.

Kamei, T., 1952: The stratigraphy of the Palaeozoic rocks of the Fukuji district, southern part of Hida Mountainland. – Journal of the Faculty of Liberal Arts and Science, Shinshu University, **1952** (2): 43–73, Matsumoto.

Kamei, T., 1955: Classification of the Fukuji Formation (Silurian) on the basis of *Favosites* with description of some *Favosites*. – Journal of the Faculty of Liberal Arts and Science, Shinshu University. **1955** (5): 39–63, Matsumoto.

Kato, M., Minato, M., Niikawa, I., Kawamura, M., Nakai, H. & Haga, S., 1980: Silurian and Devonian corals of Japan. – Acta Palaeontologica Polonica, **1980** (25): 557–566, Warszawa.

Kennard, J.M. & James, N.P., 1986: Thrombolites and stromatolites; two distinct types of microbial structures. – Palaios, **1986** (1): 492–503, Tulsa, Oklahoma.

Kobayashi, T. & Hamada, T., 1977: Devonian Trilobites of Japan. – Paleontological Society of Japan Special Paper, **20**, 202 p., Tokyo (Paleontological Society of Japan).

Kuwano, Y., 1987: Early Devonian conodonts and ostracodes from central Japan. – Bulletin of the National Science Museum, Series C, **1987** (13): 77–105, Tokyo.

Leinfelder, R.R. & Schmid, D.U., 2000: Mesozoic reefal Thrombolites and other Microbolites. – In: Riding, R. & Awramik, S.M. (Eds.): Microbial Sediments. – 289–294, Berlin, Heidelberg (Springer).

Mountjoy, E.W. & Riding, R., 1981: Foreslope stromatoporoid-renalcid bioherm with evidence of early cementation, Devonian Ancient Wall reef complex, Rocky Mountains. – Sedimentology, **1981** (28): 299–319, Amsterdam.

Niikawa, I., 1980: Geology and biostratigraphy of the Fukuji district, Gifu Prefecture, central Japan. – The Journal of the Geological Society of Japan, **1980** (86): 25–36, Tokyo.

Ohno, T., 1977: Lower Devonian Brachiopods from the Fukuji Formation, central Japan. – Memoirs of the Faculty of Science, Kyoto University, Series of geology and mineralogy, **1977**, (44): 79–126, Kyoto.

Pohler, S.M.L., 1998: Devonian buildup facies in an intra-oceanic island arc (Tamworth Belt, New South-Wales, Australia). – Facies, **1998** (39): 1–34, Erlangen.

Pratt, B.R., 1995: The origin, biota and evolution of deep-water mud-mounds : their origin and evolution. – In: Monty, C.L.V., Bosence, D.W.J., Bridges, P.H. & Pratt. B.R. (Eds.): Carbonate Mud-Mound. – International association of sedimentologists, Special publication, **23**: 49–123, Berlin.

Reid, R.P., 1987: Nonskeletal peloidal precipitates in Upper Triassic Reefs, Yukon Territory (Canada). – Journal of Sedimentary Petrology, **1987** (57): 893–900, Tulsa, Oklahoma.

Riding, R., 1977: Calcified *Plectonema* (blue-green algae), a recent example of *Girvanella* from Aldabra Atoll. – Palaeontology, **1977** (20): 33–46, London.

Riding, R., 1991: Calcareous algae and stromatolites. – In: Riding, R. (Ed.): Calcified cyanobacteria. – 55–87, Berlin (Springer).

Riding, R. & Soja, C.M., 1993: Silurian calcareous algae, cyanobacteria, and microproblematica from the Alexander Terrane, Alaska. – Journal of Palaeontology, **1993** (67): 710–728, Chicago.

Soja, C.M., 1988: Lower Devonian platform facies from Kasaan Island, southern Alaska, Alexander Terrane. – Canadian Journal Earth Sciences, **1988** (25): 639–656, Ottawa.

Sun, S.Q. & Wright, V.P., 1989: Peloidal fabrics in Upper Jurassic reefal limestones, Weald Basin, southern England. – Sedimentary Geology, **1989** (65): 165–181, Amsterdam.

Tsien, H.H., 1979: Palaeoecology of algal bearing facies in the Devonian (Couvinian to Frasnian) reef complexes of Belgium. – Palaeogeography, Palaeoclimatology, Palaeoecology, **1979** (27): 103–127, Amsterdam.

Turner, E.C., James, N.P. & Narbonne, G., 2000: Taphonomic control on microstructure in Early Neoproterozoic reefal stromatolites and thrombolites. – Palaios, **2000** (15): 87–111, Tulsa, Oklahoma.

Webb, G.E., 1996: Was Phanerozoic reef history controlled by the distribution of non-enzymatically secreted reef carbonates (microbial carbonate and biologically induced cement)? – Sedimentology, **1996** (43): 947–971, Amsterdam.

Wood, R., 2000: Palaeoecology of a Late Devonian back reef: Canning Basin, Western Australia. – Palaeontology, **2000** (43): 671–703, London.

Wray, J.L., 1977: Calcareous algae. – Developments in palaeontology and stratigraphy **14**, – 185 p., Amsterdam (Elsevier).

Plate 1

Photomicrographs of calcimicrobes and microbialite textures.

A: Encrustation with three layers, the first encrustation by *Rothpletzella* (R), followed by encrustation with dense *Girvanella* (G), and finally covered by *Wetheredella* (W). Scale bar = 1 mm.

B: Detailed features of filamentous calcimicrobe *Girvanella*. Filaments tangle together. Scale bar = 0.3 mm.

C: Accumulations of *Rothpletzella*, showing a stromatolitic texture. Scale bar = 0.4 mm.

D: Dense sheet of *Rothpletzella* intergrown with isolated, oval-shaped *Wetheredella* (arrow). Scale bar = 0.5 mm.

E: *Renalcis* is sporadically present in matrix. Scale bar = 0.5 mm.

F: Stromatolitic texture formed by accumulations of micrites. Dense micritic layers contain densely packed *Girvanella*. Scale bar = 1 mm.

G: Thrombolitic encrustation with clotted fabrics. Scale bar = 4 mm.

H: Detail of rectangle in Plate 1 (G). Peloids and dense *Girvanella* produce clots. Scale bar = 0.5 mm

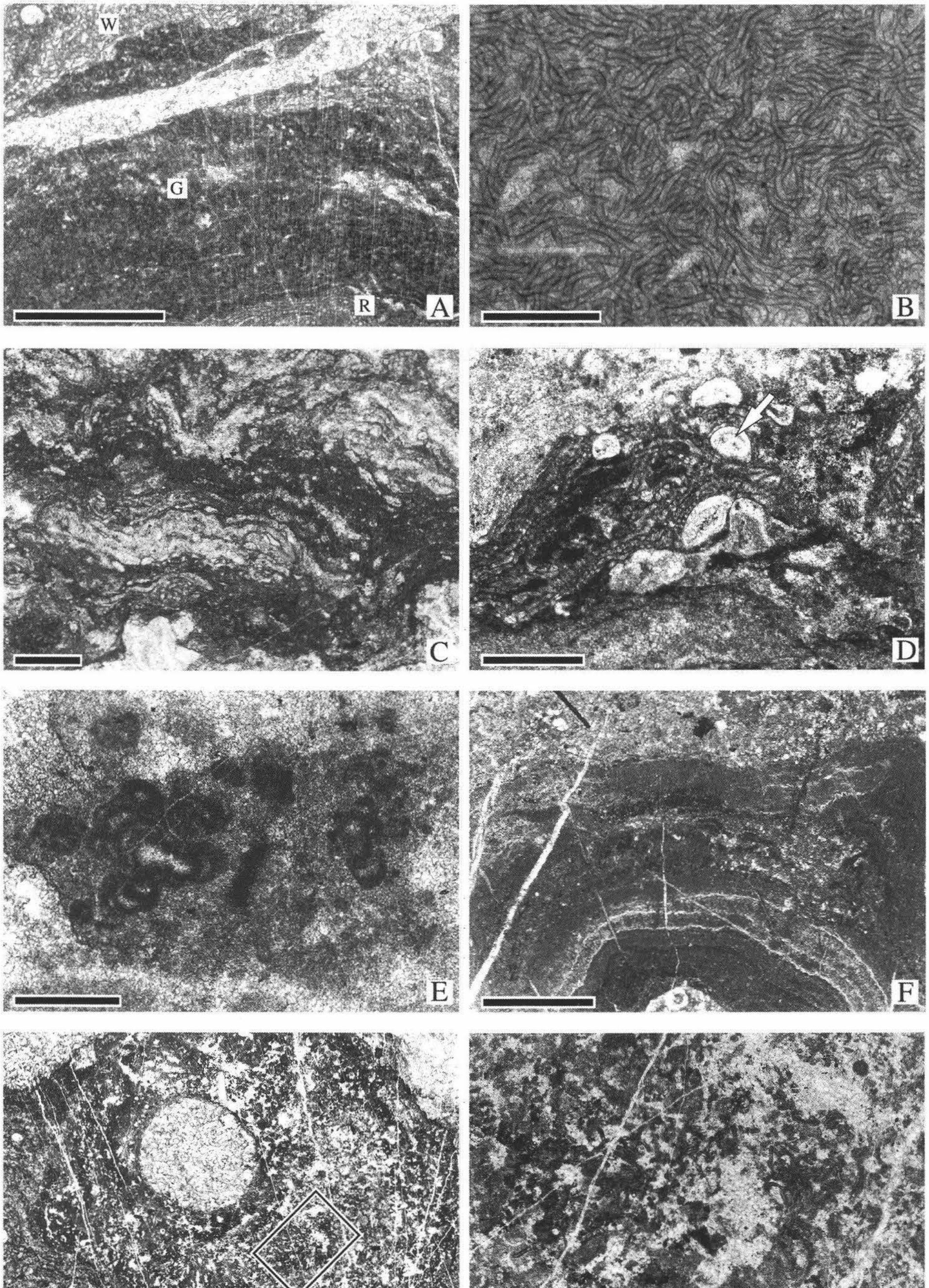

W
G
R
A
B
C
D
E
F
G
H

Plate 2

Photomicrographs of varied microbialite textures.

A: Irregular oncoidal fabric with fuzzy laminae developed around a tabulate coral. Scale bar = 4 mm.

B: Detail of arrow in Plate 2 (A). Stromatolitic textures formed by accumulations of peloids where *Girvanella* is scattered. Scale bar = 0.5 mm.

C: Cavity spaces formed by the calices of tabulate coral are filled in with peloids that show a thrombolitic texture. Scale bar = 1 mm.

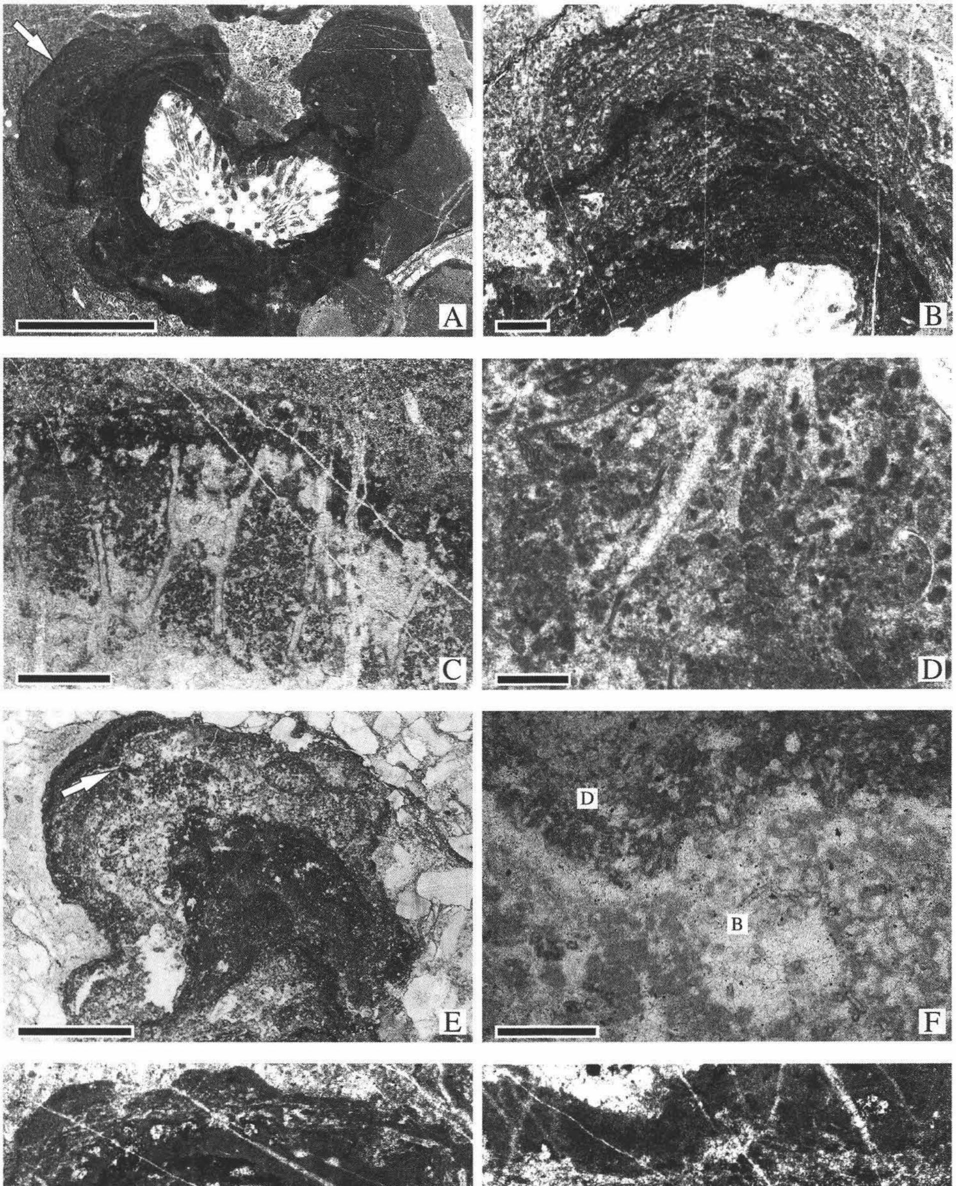
D: Peloids, tangled *Girvanella*, and their crusts are common in matrix. Some filaments are filled in with micrites. Scale bar = 0.5 mm.

E Stromatolitic texture formed by dense accumulations of *Girvanella* in crinoidal packstone. Scale bar = 2.5 mm.

F: Detail of arrow in Plate 2 (E). Dark layers (D) are composed of dense *Girvanella* with small diameters and bright layers (B) are of scarce *Girvanella* with larger diameters. Interfilament is filled with sparry cement. Scale bar = 0.2 mm.

G: Peripherally micritized crinoid core and further micrite surroundings, showing oncoids. Scale bar = 1 mm.

H: Detail of arrow in Plate 2 (G). Dense sheet of *Girvanella* is included. Scale bar = 0.5 mm.


A
B
C
D
D
B
E
F
G
H