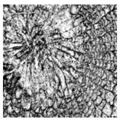
Silurian rugose corals from the Kurosegawa Terrane, Southwest Japan, and their paleobiogeographic implications

ERIKA KIDO & TETSUO SUGIYAMA



The Silurian to Devonian Gionyama Formation is assigned to the Kurosegawa Terrane in Southwest Japan. Abundant rugose corals in the Middle Member (late Llandovery to early Ludlow) of this formation represent 18 species belonging to 13 genera. These species are: *Tryplasma* sp. aff. *T. ozakii*, *Tryplasma* sp. A, *Tryplasma* sp. B, *Cystiphyllum* sp., *Holmophyllum* sp., *Holmophyllum*? sp., *Labechiellata regularis*, *Rhizophyllum* sp. A, *Rhizophyllum* sp. B, *Neobrachyelasma japonica*, *Pseudamplexus* sp., *Amsdenoides* sp., *Amplexoides* sp. aff. *A. chaoi*, *Strombodes* sp., *Nanshanophyllum hamadai*, *N. gokasense*, *Shensiphyllum* sp., and *Ptychophyllum* sp. The rugose corals from the Gionyama Formation include cosmopolitan genera that commonly occur in China, Kazakhstan, Siberia, Gotland, eastern Australia, and North America. Endemic genera, such as *Nanshanophyllum* and *Shensiphyllum*, which only occur in South China and Qaidam, are also present. Their stratigraphic ranges are restricted to the late Llandovery. The occurrences of these endemic genera may indicate a strong paleobiogeographic relation between the South China Block and 'Proto-Japan' during the Silurian. • Key words: Gionyama Formation, Kurosegawa Terrane, 'Proto-Japan', paleobiogeography, Silurian rugose corals.

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The Silurian to Devonian Gionyama Formation is exposed in the Gokase-cho, Miyazaki Prefecture, and is assigned to the Kurosegawa Terrane in Southwest Japan. Silurian corals from this formation were studied by Hamada (1959, 1961), Kato (1990), Adachi & Niko (1996), Niko (1998), and Niko & Adachi (1999a, b, 2000, 2002) and 35 species in 27 genera of tabulate corals have been documented. After Hamada (1959, 1961) reported, without illustrations, four species in four genera of rugose corals from the Gionyama Formation, the rugose corals had not been studied carefully until Kido & Sugiyama (2005) documented that abundant and diverse rugose corals, including 17 species in 12 genera, occurred in this formation. The Silurian to Devonian strata in the Kurosegawa Terrane extend into the Yokokurayama, Imose, and Mitakiyama areas in Shikoku Island (Fig. 1A). Silurian and Devonian strata are also known in the Hikoroichi and Arisu areas in the South Kitakami Terrane, and the Fukuji area in the Hida 'Gaien' Belt. The Silurian corals from the Kurosegawa Terrane have been compared with those from the South Kitakami Terrane and the Hida 'Gaien' Belt (Hamada 1961, Kido & Sugiyama 2005).

The Japanese Islands are composed of several terranes accreted one by one during the past 450 Ma along with a typical subduction zone. 'Proto-Japan' was either a marginal area of the South China Block (Isozaki 1998) or within the North China Block (Tazawa 2004). The Kurosegawa and South Kitakami terranes, and the Hida 'Gaien' Belt contain Paleozoic strata which accumulated before these two continental blocks were amalgamated, some time between the Triassic and the Early Jurassic. Paleobiogeographic information from the different terranes is important for understanding the original location of 'Proto-Japan'. Paleobiogeographic data were known from radiolarians, brachiopods, corals, and trilobites in the Silurian to Devonian strata in the Kurosegawa and South Kitakami terranes, and Hida

'Gaien' Belt (Hamada 1961, Kobayashi & Hamada 1988, Kurihara & Sashida 1998, Umeda 1996). However, information based on the Silurian rugose corals from the Kurosegawa Terrane was obviously insufficient compared with similar data from the South Kitakami Terrane. Recently, Kido (2009a, b, 2010) provided detailed taxonomic study of ten rugosan species belonging to six genera from the Gionyama Formation and described paleobiogeographic relation of these rugose corals.

Here we present the results of a careful study of the rugose corals from the Gionyama Formation, which in total revealed occurrences of 18 species in 13 genera. On the basis of our study, we concluded that 'Proto-Japan' and the South China Block were closely related during the Silurian.

All specimens of rugose corals with the abbreviation "GF. D" reported herein are deposited at Fukuoka University, Kyushu, Japan.

Geology of study area

The Gionyama Formation (Saito & Kanbe 1954) is well exposed around Mt. Gionyama, Gokase-cho, Miyazaki Prefecture in southwest Japan (Fig. 1A). Detailed geology of the western part of Mt. Gionyama is shown in Fig. 1B. The northern half of the mountain is composed of Kuraoka Igneous Rocks (Kanbe 1957) that have been dated as 450 Ma by the K-Ar method (Umeda *et al.* 1986). On the southern slope of Mt. Gionyama the Gionyama Formation is bounded by fault with the Upper Devonian, Naidaijin Formation (Fig. 1B).

Hamada (1959) divided the Gionyama Formation into four lithologic and biostratigraphic units, 'Members' G1 to G4 in ascending order. Radiolarian biostratigraphy (Umeda 1997) and a sedimentological study of the limestone conglomerate indicate that these subdivisions are not suitable. Kido & Sugiyama (2007) divided this formation, on the basis of lithostratigraphy, into three members: Lower, Middle, and Upper (Figs 1B, 2). The Lower Member is exposed only on the western slope of Mt. Gionyama as shown in Figs 1B and 2. This member is bounded by a fault with the Middle Member of the Gionyama Formation. The relationship of the contact between the Middle and Upper members is not clear in the western part of Mt. Gionyama, but the boundary may be sharp as a transitional facies is not observed.

Lower Member

The Lower Member (over 100 m thick) is mostly sandstone with intercalations of greenish siliceous tuff. This member is correlative with the G1 Member and the lowest part of G2 Member as designated by Hamada (1959). The true thickness of the Lower Member is unknown because the exposed base of this member is bounded with the Kuraoka Igneous Rocks by faults. Wakamatsu *et al.* (1990) described the late Llandovery to Wenlock radiolarians from the Lower Member.

Middle Member

The Middle Member (about 300 m thick) is a limestone conglomerate intercalated with thin lenticular tuffaceous shales or sandstones. Some of the limestone conglomerates are supported by non-calcareous clastics with greenish to yellowish brown color, which are equivalent to the G2 facies limestones of Hamada (1959). Other limestone conglomerates are massive with stylolitization caused by pressure solution and contain a few non-calcareous matrices or none at all. This non-calcareous matrices show green to yellow, pink to purple, or gray color. These conglomerates are exposed on the slope of Mt. Gionyama as a thick wall and represent the G3 facies limestones described by Hamada (1959). The limestone conglomerate of the Middle Member is very fossiliferous, with corals, crinoids, bryozoans, stromatoporoids, brachiopods, trilobites, bivalves, cephalopods, and gastropods (Hamada 1961, Kido & Sugiyama 2005). The bed of limestone conglomerates which are massive and contain none or a few non-calcareous matrices does not overlie the bed of limestone conglomerate supported by non-calcareous matrices as interpreted by Hamada (1959). The latter bed is interbedded with the former and in some cases pinches out laterally (Figs 1B, 2A). These lithologic characteristics suggest that the limestone conglomerates of the Middle Member were transported from shallow reefal area as debris flows and deposited on a reef slope or along a reef front where deposition of acidic tuffs was dominant (Kawamura *et al.* 2003, Kido & Sugiyama 2007). The geological age of the Middle Member is late Llandovery to early Ludlow based on the corals described in this study.

Upper Member

The Upper Member (up to a maximum of 450 m thick) is mainly composed of acidic tuff. This member is equivalent to the G4 Member of Hamada (1959). Umeda (1997) found radiolarian assemblages in this member and reported an age ranging from the late Wenlock to early Middle Devonian. Additionally, he suggested that, based on the age of radiolarian, part of the Upper Member might be a contemporaneous heterotopic facies of the limestone conglomerates of the Middle Member.

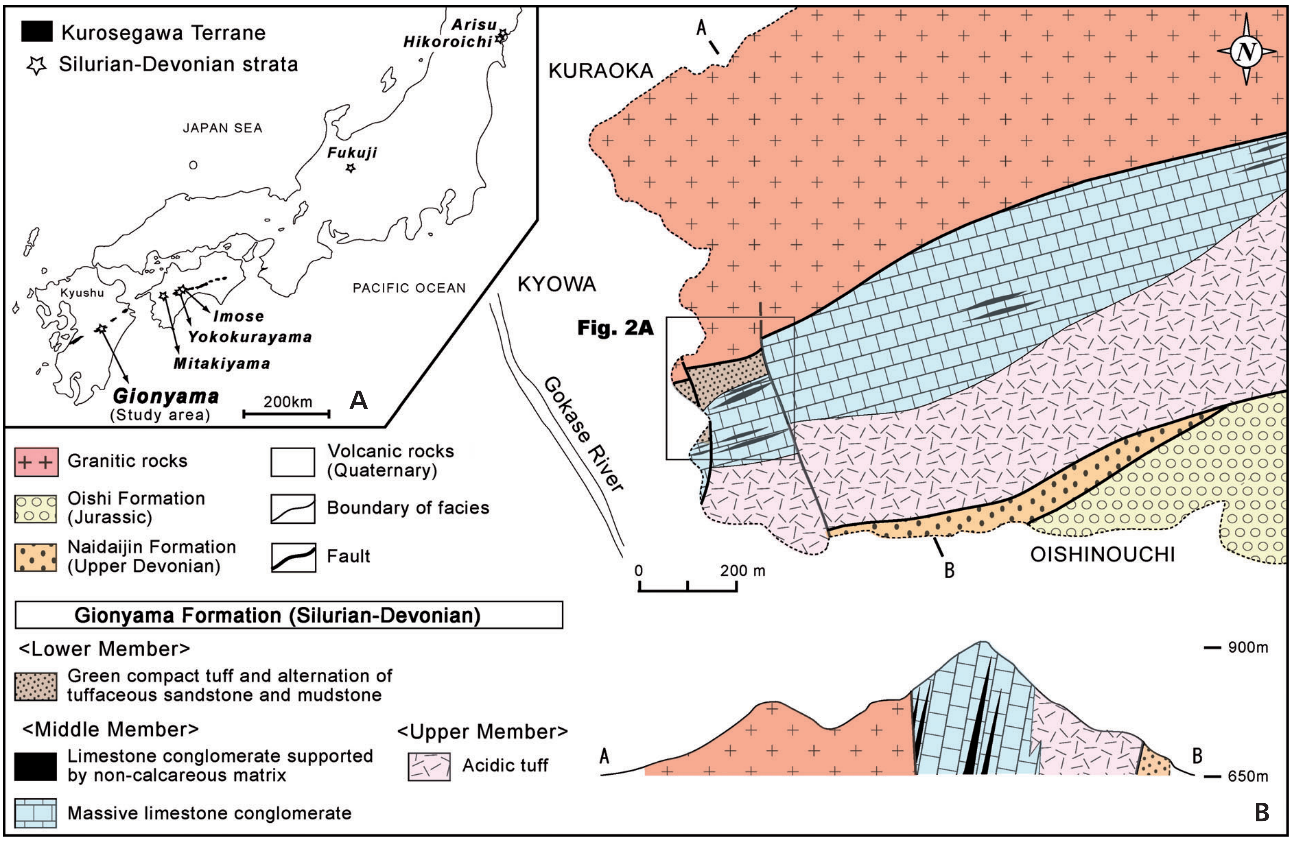

Figure 1. A – index map showing distribution of the Kurosegawa Terrane, study area (Gionyama), and the localities of Silurian to Devonian strata in Japan. • B – geological map with cross section of the western part of Mt. Gionyama. Modified from Kido (2009a).

Coral occurrences and their correlation

Silurian rugose corals reported in this paper were collected from four localities, KL1 to 4, in the Middle Member exposed on the southwestern slope of Mt. Gionyama (see Fig. 2A). The stratigraphic positions of these localities are provided in Fig. 2B. The rugose coral species of each locality are listed in Fig. 3 (the number of obtained specimens is given in parentheses). Distinctive sections of some corals (*Tryplasma* sp. aff. *T. ozakii*, *Tryplasma* sp. A, *Tryplasma* sp. B, *Cystiphyllum* sp., *Rhizophyllum* sp. A, *Rhizophyllum* sp. B, *Strombodes* sp. and *Ptychophyllum* sp.) are illustrated in Fig. 4. Regarding other rugose corals, the reader is referred to illustrations in Kido (2009a, b, 2010).

Hamada (1959) divided the fossiliferous calcareous part of the Gionyama Formation into the lower G2 Member and the upper G3 Member. He mentioned the different biostratigraphic characteristics of the G2 and G3 members; the G2 characterized by *Falsicatenipora shikokuensis*, *Acanthohalysites kuraokensis*, and *Coronocephalus kobayashii*, and the G3 containing *Schedohalysites kitakamiensis*, *Zelophyllum* sp., and *Conchidium* sp. cf. *C. knightii*. Hamada (1959) correlated the G2 Member with upper Wenlock and the G3 with the lower Ludlow.

However, these two members are limestone conglomerates containing different amount of non-calcareous matrices, and they are interbedded and pinch out laterally. Additionally the corals in these two limestone conglomerates are similar. The tabulate corals *Falsicatenipora shikokuensis* and *Acanthohalysites kuraokensis*, as well as *Schedohalysites kitakamiensis* occur at Loc. KL1. This study treats the fossiliferous limestones as a single stratigraphic unit of the Middle Member.

Correlation based on rugose corals

Among the rugose corals found during this study, *Nanshanophyllum* and *Shensiphyllum* are useful for determining the geological age of the Middle Member (Kido 2009a). *Nanshanophyllum* is reported from the upper Llandovery and occurs in the Ningqiang Formation of the Guangyuan, Sichuan (He 1978), the Xiushan Formation of the Shimen, Hunan (Ge & Yü 1974), the Zhugqu Group of the Zhugqu, Gansu (Cao & Lin 1982), and the Daluzhai Formation of the Daguan, Yunnan (Chen *et al.* 2005) and from the upper Llandovery to the lower Wenlock of the Quannaogou Formation of the Yumen, Gansu (Yü 1956). *Shensiphyllum* is

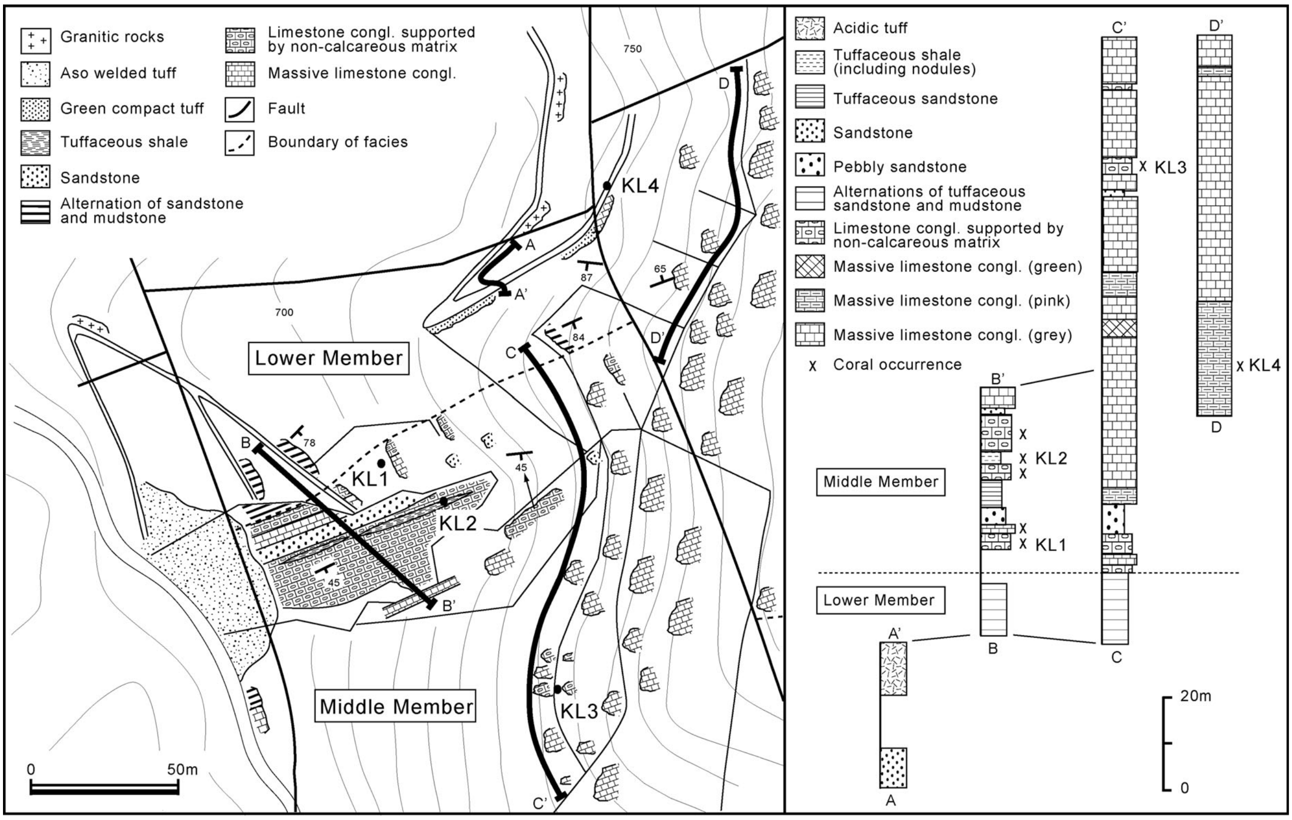

Figure 2. A – collecting sites of corals (KL1 to 4), location of measured columnar sections (A-A' to D-D'), and exposures of the Lower and Middle members of the Gionyama Formation on the western slope of Mt. Gionyama. • B – measured columnar sections, A-A' to D-D', as indicated in Fig. 2A. Sections show the lithologic character and stratigraphic position of coral localities (KL1-4). Slightly modified from Kido (2009a).

KL4	*Tryplasma* sp. B (1)
KL3	*Nanshanophyllum gokasense* Kido, 2009a (1)
KL2	*Cystiphyllum* sp. (1) *Neobrachyelasma japonica* Kido, 2010 (43) *Amplexoides* sp. aff. *A. chaoi* (Grabau, 1925) (39) *Nanshanophyllum hamadai* Kido, 2009a (18)
KL1	*Tryplasma* sp. aff. *T. ozakii* Sugiyama, 1940 (24) *Tryplasma* sp. A (1) *Tryplasma* sp. B (4) *Cystiphyllum* sp. (3) *Holmophyllum* sp. (4) *Holmophyllum*? sp. (2) *Labechiellata regularis* (Sugiyama, 1939) (12) *Rhizophyllum* sp. A (4) *Rhizophyllum* sp. B (6) *Pseudamplexus* sp. (1) *Amsdenoides* sp. (1) *Strombodes* sp. (13) *Nanshanophyllum gokasense* Kido, 2009a (14) *Shensiphyllum* sp. (1) *Ptychophyllum* sp. (1)

Figure 3. Rugose corals collected from the four localities, KL1 to 4. Number of specimens examined in each species is shown in parentheses.

known from the upper Llandovery of South China and occurs in the Ningqiang Formation of the Ningqiang-Guangyuan area near the border of Shaanxi and Sichuan (Ge & Yü 1974, He 1978) and the Daluzhai Formation of the Daguan, Northeast Yunnan (Chen *et al.* 2005). Scrutton & Deng (2002) and Chen *et al.* (2005) compiled the occurrences of *Nanshanophyllum* and *Shensiphyllum* and re-examined their stratigraphic ranges. Based on their compilation, in China, these two genera occur only in the *Monoclimacis griestoniensis-M. crenulata* graptolite biozones which are related to the middle to late Telychian in the late Llandovery.

Nanshanophyllum hamadai was also found in the Fukata Formation of the Yokokurayama Group (Umeda 1998) in the Kurosegawa Terrane, which is exposed in the Yokokurayama area of Shikoku Island (Fig. 1A). Hamada (1959) correlated his G2 and G3 members of the Gionyama Formation with the Fukata Formation based on halysitid corals. Kuwano (1976) suggested that the geological age of the Fukata Formation ranged from the late Llandovery to the early middle Ludlow based on conodonts such as *Ambalodus galerus*, *Ozarkodina excavata excavata*, *Pterospathodus amorphognathoides*, and *Panderodus* sp. Rong & Chen (2003) regarded *A. galerus* as a critical element for

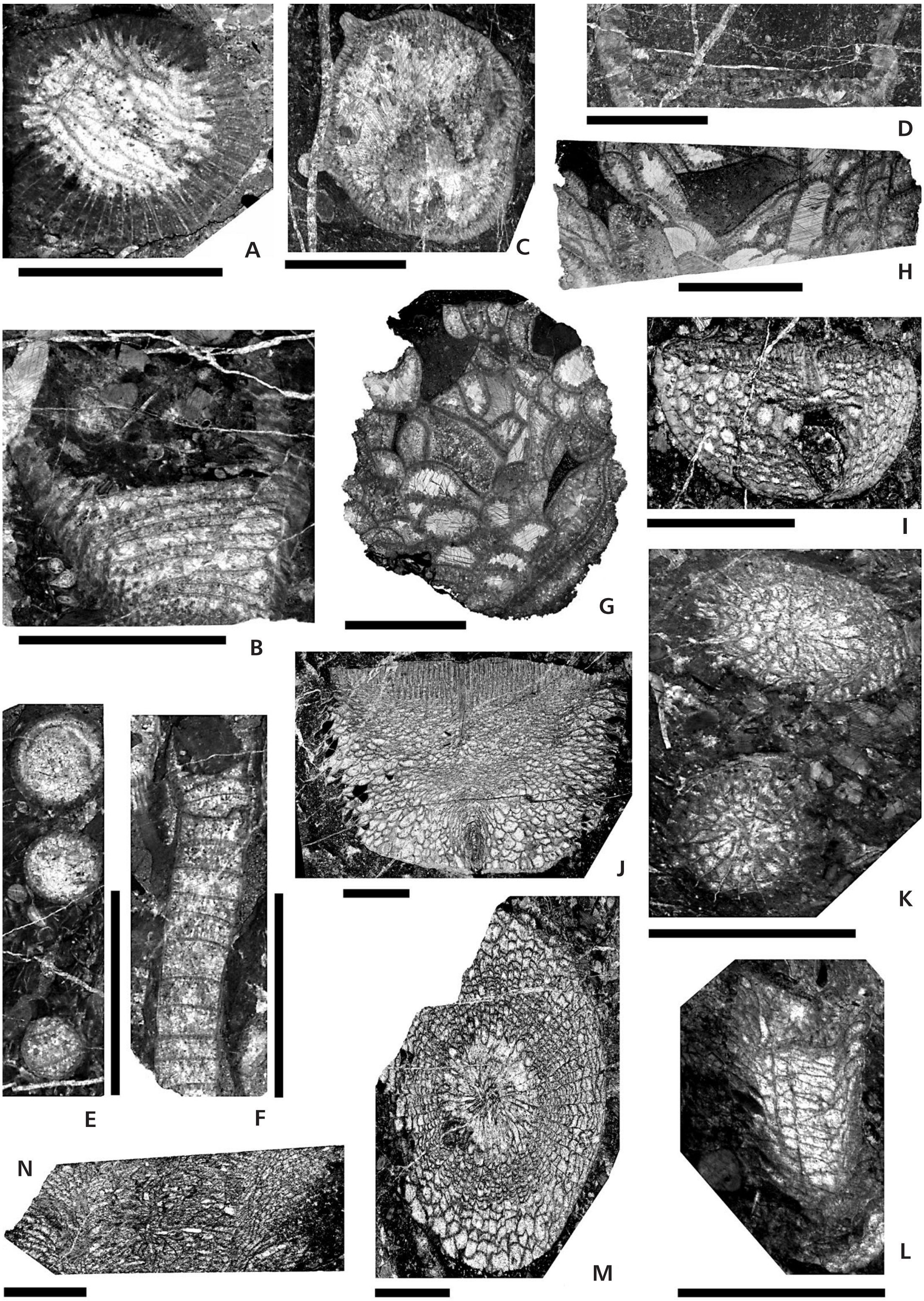

Figure 4. A, B – *Tryplasma* sp. aff. *T. ozakii* Sugiyama. • A – transverse section, B – longitudinal section, GF. D 25141a, 25158b, respectively, Loc. KL1. • C, D – *Tryplasma* sp. A. C – transverse section, D – longitudinal section, GF. D 25142a, c, respectively, Loc. KL1. • E, F – *Tryplasma* sp. B. E – transverse section, F – longitudinal section, GF. D 25143a, Loc. KL4. • G, H – *Cystiphyllum* sp. G – transverse section, H – longitudinal section, GF. D 25145c, d, respectively, Loc. KL 2. • I – *Rhizophyllum* sp. A. Transverse section, GF. D 21005, Loc. KL1. • J – *Rhizophyllum* sp. B. Transverse section, GF. D 25146, Loc. KL1. • K, L – *Strombodes* sp. K – transverse section, L – longitudinal section, GF. D 25147b, 25149b, respectively, Loc. KL1. • M, N – *Ptychophyllum* sp. M – transverse section, N – longitudinal section, GF. D 25148a, b, respectively, Loc. KL1. All scale bars equate to 10 mm.

Rugose coral genera from Japanese Silurian \ Region	Kurosegawa Terrane: Gionyama area	Kurosegawa Terrane: Yokokura-yama area	Kurosegawa Terrane: Imose area	Kurosegawa Terrane: Mitakiyama area	Hida-'Gaien' Belt: Hitoegane area	South Kitakami Terrane: Hikoroichi area	South Kitakami Terrane: Shimoarisu area
Cyathophylloides						○	
Pilophyllum						○	
Neocystiphyllum						○	
Spongophyllum						○	
Kitakamiphyllum						○	
Hedstroemophyllum		○	○				
Nipponophyllum						○	
Zaphrentid			○	○			
Tryplasma	○	○		○		○	○
Cystiphyllum	○					○	
Holmophyllum	○	○					
Labechiellata	○	○	○			○	
Rhizophyllum	○	○			○	○	○
Kodonophyllum	○						
Neobrachyelasma	○						
Pseudamplexus	○						○
Amsdenoides	○					○	○
Pycnostylus	○						
Zelophyllum	○						
Amplexoides	○	○					
Strombodes	○						
Nanshanophyllum	○	○					
Shensiphyllum	○						
Ptychophyllum	○						

Figure 5. Silurian rugose corals from Japan, based on Sugiyama (1940), Hamada (1961), Kato *et al.* (1980) and present study. Circle indicates the presence of each rugosan genus, and a horizontal line connecting circles indicates a common occurrence of rugosan genera in the different areas.

Rugose coral genera \ Formation	Japan: Gionyama Formation	South China: Ningqiang Formation	South China: Xiushan Formation	South China: Daluzhai Formation	Qaidam: Quannaogou Formation
Rhabdocyclus				□	
Aphyllum		□			
Maikottia		□			
Cysticonophyllum		□			
Hedstroemophyllum		□			
Microplasma		□			
Nipponophyllum		□			
Pilophyllia		□		□	
Mucophyllum		□			
Gyalophylloides		□		□	
Gyalophyllum		□	□		
Ceriaster		□			
Kyphophyllum		□			□
Micula?		□			
Miculiella		□			
Pseudophaulactis				□	
Chonophyllum		□			
Idiophyllum		□			
Dinophyllum		□			□
Ningqiangophyllum		□			
Dokophyllum		□			
Tabularia		□		□	
Oliveria		□		□	
Tryplasma	○	□			□
Cystiphyllum	○	□			□
Holmophyllum	○	□			
Labechiellata	○	□			
Rhizophyllum	○	□			
Kodonophyllum	○	□			
Neobrachyelasma	○	□			
Pseudamplexus	○	□			
Amsdenoides	○	□			
Pycnostylus	○	□			
Zelophyllum	○	□		□	□
Amplexoides	○	□			
Strombodes	○	□			
Nanshanophyllum	○	□	□	□	□
Shensiphyllum	○	□		□	
Ptychophyllum	○	□			

Figure 6. Rugose corals from the Gionyama Formation and the Telychian strata in South China and Qaidam, from Hamada (1961), Chen *et al.* (1991), Scrutton & Deng (2002), He & Chen (2004), Chen *et al.* (2005), and this study. Circles or squares indicate coral occurrences in the Gionyama Formation or in the Telychian strata in China, respectively. Lines connecting circles and squares indicate a common occurrence of rugosan genera between the Gionyama Formation and the Telychian strata in China.

recognizing the late Llandovery in the Xiushan Formation which yields *Nanshanophyllum*. Therefore, the conodont date from the Fukata Formation and occurrences of *Nanshanophyllum* and *Shensiphyllum* from the Middle Member of the Gionyama Formation indicate that the geological age of the Middle Member should extend downward to, at least, the late Llandovery. The other corals from the Middle Member have relatively long geologic ranges, from the late Llandovery to the early Ludlow at least. The range of these corals is also supported by conodont date from the Fukata Formation.

A comparison of the Silurian rugose corals from the Gionyama area with those from other Japanese localities is presented in Fig. 5. The corals, *Kodonophyllum*, *Pycnostylus* and *Zelophyllum*, which were reported by Hamada (1961) from his G3 facies limestone, are added in the list of rugose corals from the Gionyama area. Rugose coral genera from the Kurosegawa Terrane have been compared with those from other Silurian localities in the Hida 'Gaien' Belt and the South Kitakami Terrane (Hamada 1961, Kido & Sugiyama 2005). Kato *et al.* (1980) reported *Rhizophyllum* from the Hitoegane limestone in the Fukuji area of the Hida 'Gaien' Belt, and Kobayashi & Hamada (1974) reported the trilobite *Encrinurus* from this unit in this region. Based on these fossils, the age of this limestone was considered to be late Silurian (Kato *et al.* 1980). However, Kurihara (2004) pointed out that the Hitoegane limestone is a xenolith in a serpentinite. Thus, relationship between the corals in the Gionyama Formation and this limestone is questionable. A comparison of rugose coral genera from the Kawauchi Formation in the Hikoroichi area of the

Rugose coral genera \ Formation or Assembrage	Japan: Gionyama Formation	Eastern Australia: Bridge Creek Assemblage	Eastern Australia: Quarry Creek Assemblage	Eastern Australia: Dripstone Assemblage	Eastern Australia: Hattons Corner Assemblage
Primitophyllum?		□			
Cantrillia		□			
Aphyllum			□	□	□
Stortophyllum			□		
Cysticonophyllum		□			
Hedstroemophyllum			□	□	□
"*Microplasma*"			□		
Coronoruga				□	
Nipponophyllum				□	□
Lambeophyllum?		□			
Calostylis		□			
Streptelasma		□			
Plektelasma			□		
Grewingkia		□	□		
Cystipaliphyllum		□			
Dinophyllum				□	
Palaeocyathus					□
Spinocarina			□		
Mucophyllum					□
Stylopleura				□	□
Multicarinophyllum					□
Palaeophyllum			□	□	
Multicarinophyllum				□	
Lindstroemophyllum?			□		
Pilophyllum				□	
Detilasma		□	□		
Dokophyllum			□		□
Ketophylloides?		□			
Tabularia		□			
Mictocystis			□		
Yassia					□
Entelophyllid			□		
Entelophyllum				□	□
Angullophyllum			□		
Arachnophyllum			□	□	
Idiophyllum					□
Zenophila					□
Bungoniella				□	
Amplistela			□		
Phaulactis			□	□	□
Neomphyma?			□		
Toquimaphyllum					□
Cyathactis			□		
Zelolasma?					□
Burota			□		
Tryplasma	○	□	□	□	□
Cystiphyllum	○	□	□		
Holmophyllum	○		□		
Labechiellata	○		□	□	
Rhizophyllum	○		□		□
Kodonophyllum	○				
Neobrachyelasma	○				
Pseudamplexus	○		□		
Amsdenoides	○				
Pycnostylus	○		□	□	□
Zelophyllum	○				
Amplexoides	○	□	□		
Strombodes	○		□		
Nanshanophyllum	○				
Shensiphyllum	○				
Ptychophyllum	○			□	□

Figure 7. Rugose corals from the Gionyama Formation compared to the four coral assemblages which are recognized in eastern Australia (Pickett 1982, Pickett *et al*. 2000, Strusz & Munson 1997). Circles or squares indicate Silurian rugosan genera in the Gionyama Formation or in the coral assemblages of eastern Australia.

South Kitakami Terrane with those in the Gionyama Formation shows that there are five genera in common: *Tryplasma*, *Cystiphyllum*, *Labechiellata*, *Rhizophyllum*, and *Amsdenoides*. There are no rugose coral genera in the South Kitakami Terrane that indicate a late Llandovery age. It seems more reasonable to suggest that the Kawauchi Formation is Wenlock to Ludlow in age.

Paleobiogeographic implications

Based on the occurrences of the tabulate corals such as *Falsicatenipora* and *Schedohalysites* from the Kurosegawa and South Kitakami terranes, some affinities between the Japanese Silurian corals and those from South China and Australia were suggested by Hamada (1961) and Kato (1990). According to Hill (1981) and Scrutton & Deng (2002), *Falsicatenipora* occurs in the upper Llandovery of Ningqiang-Guangyuan area in South China and the Wenlock to Ludlow of New South Wales and Queensland, eastern Australia. *Schedohalysites* is reported from the upper Llandovery of New South Wales, Australia and the Ningqiang-Guangyuan area, and from the Wenlock to Ludlow of China, Australia, India, and Gotland (Hill 1981). However, Young & Elias (1995) and Mõtus (2005) mentioned that the morphological definition of *Schedohalysites* by Hamada (1957) was questionable. Further consideration of biotic affinity based on this tabulate coral requires more careful taxonomic study.

Niko & Adachi (2000, 2004) reported the tabulate corals, *Mesosolenia decorasa* and *Egosiella* sp. cf. *E. ningqiangensis*, from the Gionyama Formation, which also occurred in the Silurian of the Daba Shan Mountains in the Sichuan-Shaanxi border area. They suggested an affinity of tabulate coral faunas between the Gionyama Formation and the Daba Shan Mountains.

Kato (1990) reported compound rugose corals, *Nipponophyllum* and *Labechiellata*, together with the tabulate corals like halysitids and favositids, from the Kawauchi Formation and suggested that these compound corals could indicate the location of paleo-equator during the Silurian and stated that the tropical distribution of these corals was parallel to the paleo-equator during the Wenlock.

The biostratigraphy and sedimentary facies of the Lower Silurian of China were revised precisely based on occurrences of conodonts and graptolites, and the Silurian paleogeography in China was adjusted based on these revisions (Rong & Chen 2003, Scrutton & Deng 2002). Furthermore, these revisions resulted in new lists of coral occurrences for each locality and each stratigraphic unit in the Silurian of China. The rugose corals from the Gionyama Formation are similar to those from the upper Llandovery strata of South China (see Fig. 6). All the rugose coral genera from the Gionyama Formation occur in the Ningqiang Formation of the Ningqiang-Guangyuan area at the northwestern margin of the South China Block. Some genera from the Gionyama Formation also occur in the upper Llandovery of the Xiushan and Daluzhai formations of South China, and the Quannaogou Formation of Qaidam (Fig. 6). Additionally, 13 genera of tabulate corals among 38 genera reported from the Ningqiang Formation also occur in the Gionyama Formation (Hamada 1961; Niko & Adachi 2000, 2004; Scrutton & Deng 2002).

The Gionyama Formation yields rugosan genera that are also documented from equivalent formations in Tarim and North China. A comparison of rugosan genera from the Wenlock to Ludlow of Tarim (Wang *et al*. 2001) with those from the Gionyama Formation shows that in both areas same five genera appear. They are *Tryplasma*, *Cystiphyllum*. *Zelophyllum*, *Amplexoides* and *Ptychophyllum*. Six genera such as *Tryplasma*, *Holmophyllum*, *Zelophyllum*, *Amplexoides*, *Strombodes* and *Ptychophyllum* from the Gionyama Formation are also known from the Wenlock and upper Silurian of North China (Guo 1976, 1980; Li *et al.* 1985). On the other hand, the rugose corals from the Llandovery to Ludlow of Hainan, Tibet and West Sichuan-East Xizhang region seem to have only a few genera in common with those from the Gionyama Formation (Deng & Zhang 1984, Wang *et al.* 2005, Wu *et al.* 1982).

The rugose coral genera from the Gionyama Formation also commonly occur in the Silurian of Australia. Four successive coral assemblages in the Silurian of New South Wales and Queensland, eastern Australia are recognized (Pickett 1982, Pickett *et al*. 2000, Strusz & Munson 1997). They are the Bridge Creek assemblage (early to middle Llandovery), the Quarry Creek assemblage (late Llandovery to early Wenlock), the Dripstone assemblage (early Wenlock to early Ludlow), and the Hattons Corner assemblage (early Ludlow to Přídolí) in ascending order. The Gionyama Formation includes nine genera that are known in the Quarry Creek assemblage and four genera that are documented in the Dripstone assemblage (see Fig. 7).

The present study reveals that the rugose corals from the Gionyama Formation include both cosmopolitan genera and endemic genera such as *Shensiphyllum*, *Nanshanophyllum*, which occur only in South China, Qaidam and Japan. The occurrences of *Shensiphyllum* and *Nanshanophyllum* from the Gionyama Formation may indicate that a paleogeographic connection between the South China Block and Kurosegawa Terrane existed during the Silurian. The genus *Shensiphyllum* is characterized by having a fasciculate corallum with carinate septa that swell into a lenticular shape at the boundary of tabularium and dissepimentarium, tabularium divided into convex inner and concave outer series, and dissepimentarium including a one row of longitudinal series of horseshoe dissepiments (Kido 2009a). In China, ten species which occurred in the Ningqiang Formation (Shaanxi-Sichuan), Shamao Formation (Hubei), Daluzhai Formation (Northeast Yunnan) and Wangjiawan Formation (Sichuan) were assigned to *Shensiphyllum* (Chen *et al*. 2005, Ge & Yü 1974, He 1978, Li *et al.* 1975, Scrutton & Deng 2002, Tang 2006). Among them, the species except for the one from the Wangjiawan Formation have one series of horseshoe dissepiments with a few series of subglobose or elongate dissepiments within dissepimentarium. In the species such as *Shensiphyllum aggregatum* Ge & Yü, 1974 (type species of the genus) and *S. guangyuaense* He, 1978 from the Ningqiang Formation, and *S. minor* Chen, He & Tang, 2005 from the Daluzhai Formation one series of horseshoe dissepiments is developed in the outer part of dissepimentarium. One series of horseshoe dissepiments in *Shensiphyllum phacelloides* (Cao *in* Li *et al.* 1975) and *Shensiphyllum* sp. reported by Scrutton & Deng (2002) from the Ningqiang Formation, and *S. hubeiense* (Wu *in* Jia & Wu 1977) from the Shamao Formation occurs in the middle part of dissepimentarium. Kido (2009a) indicated that the location of one series of horseshoe dissepiments within the dissepimentarium could be used to separate these species into two different groups. Three species described by Tang (2006) from the Wangjiawan Formation, *Shensiphyllum intermedium* Tang, 2006, *S. proliferum* Tang, 2006 and *S. simplex* Tang, 2006, may be also assigned to an other group which is related to the staurioid rugose corals. The dissepimentarium in *Shensiphyllum intermedium* is composed of one row of horseshoe dissepiments and one to two rows of subglobose, small dissepiments developed in the outer or inner side of them in the single corallum. *Shensiphyllum proliferum* has one row of horseshoe dissepiments which are irregularly accompanied by one to two rows of subglobose, declined dissepiments in the outer or inner side of them. The dissepimentarium in *Shensiphyllum simplex* is generally composed of one series of horseshoe dissepiments, but in some corallites longitudinal series of flat dissepiments are developed between them and the wall. *Shensiphyllum* sp. (see Kido 2009a, figs 11.9–11.13, 12) which occurs in the Gionyama Formation is characterized by possessing one row of horseshoe dissepiments in the outer part of the dissepimentarium, as well as *S. aggregatum*, *S. guangyuaense* and *S. minor*. Only these four species are assigned to *Shensiphyllum* here.

Nanshanophyllum was previously restricted to the upper Llandovery of South China (Shaanxi-Sichuan, Northeast Yunnan, Hunan and Southeast Gansu) and Qaidam

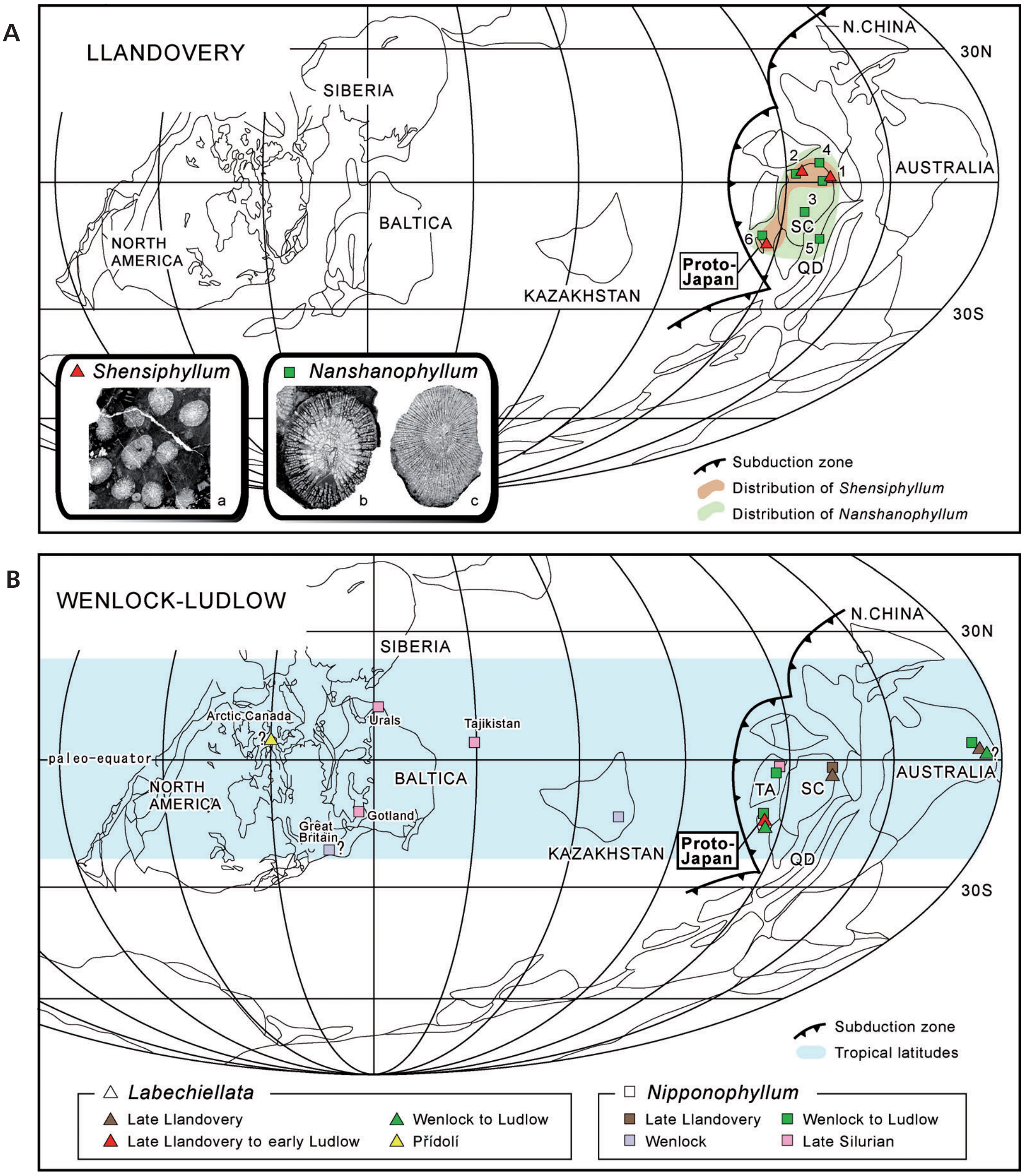

Figure 8. A – paleogeographic distribution of *Shensiphyllum* and *Nanshanophyllum* during the late Llandovery. Triangles with red color indicate the locations of *Shensiphyllum* and squares with green color indicate the locations of *Nanshanophyllum*. 1. Ningqiang-Guangyuan (Shaanxi-Sichuan), 2. Daguan (NE Yunnan), 3. Shimen (Hunan), 4. Zhugqu (SE Gansu), 5. Yumen (NW Gansu), 6. Kurosegawa Terrane. a – *Shensiphyllum* sp. GF. D 25039-1, Loc. KL1, Gionyama Formation, b – *Nanshanophyllum hamadai*. GF. D 25006a, Loc. KL2, Gionyama Formation, c – *N. gokasense*. GF. D 25028, KL1, Gionyama Formation. • B – paleogeographic distribution of *Labechiellata* and *Nipponophyllum*. Triangles indicate the locations of *Labechiellata* and squares indicate the locations of *Nipponophyllum*. Different ages are shown by different colors in triangles and squares. Abbreviations: SC – South China, QD – Qaidam, TA – Tarim. The geographical range of the tropical latitudes is based on Kiessling *et al*. (2003). Llandovery and Wenlock-Ludlow paleo-maps are modified from Golonka (2002) and Kiessling *et al*. (2003).

(Northwest Gansu). Hill (1981) considered *Nanshanophyllum* as a solitary coral with carinate septa and included the following three species in *Nanshanophyllum*: *Stereoxylodes multicarinatus* and *Stereoxylodes*? sp. described by McLean (1975) from the upper Llandovery of New South Wales, Australia and *Stereoxylodes* (*Nanshanophyllum*) sp. described by Pedder (1976) from the Upper Silurian (Přídolí) of Arctic Canada. However, *Nanshanophyllum* is distinguishable from those species in having bilateral symmetry in septal arrangement and a "pseudo"-axial structure (Kido 2009a, figs 6, 8, 10, 11.1–11.8). Morphologically *Nanshanophyllum hamadai* and *N. gokasense* from the Gionyama Formation resemble *N. typicum* and *N. mirandum* which were described by Yü (1956, 1962) from the Quannaogou Formation of Northwest Gansu, respectively (for detailed taxonomy see Kido 2009a).

Neobrachyelasma is also expected to be an endemic taxon. It is known from the: (1) upper Llandovery of Sichuan and Hubei, South China (Cao & Lin 1982, Chen *et al.* 2005, Scrutton & Deng 2002), (2) Wenlock to Ludlow of the Altai, southwest Siberia (Ivanovskiy & Kulkov 1974, Zheltonogova 1965), and (3) Ludlow of Balkhash, Kazakhstan (Nikolaeva 1960, Sytova 1966). In addition, *Dinophyllum stokesi* and *D. estonicum* described by Sultanbekova (1986) from the lower Llandovery of Kazakhstan should be assigned to *Neobrachyelasma*. Figured materials of these two species have twisted major septa and incomplete tabulae with concave floors in the axial area, a characteristic of *Neobrachyelasma*. *Neobrachyelasma japonica* (Kido 2010, figs 3, 4.1–4.6, 6) from the Gionyama Formation shows similarity with specimen from the upper Llandovery of South China. Perhaps *Neobrachyelasma* appeared in Kazakhstan during the early Llandovery, migrated to South China and Japan (Gionyama area) in the late Llandovery, and then to Siberia during the Wenlock to Ludlow. The interpretation of the migration of *Neobrachyelasma* may also suggest paleogeographic proximity between the South China and the Kurosegawa Terrane during the late Llandovery (Kido 2010).

Cosmopolitan coral genera of the Gionyama Formation including *Tryplasma*, *Cystiphyllum*, *Holmophyllum*, *Labechiellata*, *Rhizophyllum*, *Pseudamplexus*, *Amsdenoides*, *Amplexoides*, *Strombodes*, and *Ptychophyllum* commonly occur in South China, Qaidam, North China, Tarim, Kazakhstan, Gotland, Siberia, eastern Australia, and North America. *Amplexoides* sp. aff. *A. chaoi* (Kido 2010, figs 4.11–4.17, 9) in the Gionyama Formation is similar to *A. chaoi* reported from the Lower Silurian of South China (Hubei, Guizhou and Southeast Gansu). Among the holmophyllids in the Gionyama Formation, *Holmophyllum*? sp. seems to have some similarities to the species which occur in the upper Llandovery and ?lower Ludlow of eastern Australia (New South Wales), the Wenlock and Upper Silurian of China (Xinjiang and Inner Mongolia), and the Silurian of North America (Maine). Another holmophyllid, massive thamnasterioid coral, *Labechiellata*, is known in Japan (South Kitakami and Kurosegawa terranes), upper Llandovery of China (Shaanxi-Sichuan), upper Llandovery, ?Wenlock and ?Ludlow of eastern Australia (New South Wales), Lower Devonian of Central Kazakhstan, and possibly ?Přídolí of Arctic Canada. The Gionyama species has close similarities with *Labechiellata currani* (Wright *in* Wright & Bauer 1995) from New South Wales of eastern Australia (see Kido 2009b). The affinities of species like *Amplexoides*, *Holmophyllum* and *Labechiellata* in the Gionyama Formation may indicate a paleobiogeographic relation between 'Proto-Japan' and those other areas where similar species occur.

Paleogeographic distributions of the endemic genera, *Shensiphyllum* and *Nanshanophyllum*, are plotted on the Llandovery paleo-map as shown in Fig. 8A. Additionally, cosmopolitan genera which occur as compound forms, such as *Labechiellata* and *Nipponophyllum*, are plotted on the Wenlock to Ludlow paleo-map in Fig. 8B. *Nipponophyllum* appears in Northeast Japan (South Kitakami Terrane), upper Llandovery of Shaanxi, China, Wenlock of Kazakhstan, ?Wenlock of Great Britain, upper Wenlock, lower or middle Ludlow of New South Wales, Australia, upper Ludlow of Eastern Urals and Gotland, Sweden, and the Upper Silurian of Tajikistan (Kato 1982). Recently, Wang *et al*. (2001) also reported the occurrence of this genus from the Wenlock to Ludlow and the Přídolí of Xinjiang (South Tianshan region), China. In the Silurian of the Kurosegawa and South Kitakami terranes, tabulate corals such as favositids and halysitids commonly occur together with compound holmophyllid rugose corals. These compound corals may indicate tropical environments as proposed by Kato (1990) and suggest that 'Proto-Japan' was located in sub-tropical to tropical latitudes during the Silurian, together with the other areas that yield these corals (see Fig. 8B).

The paleo-maps shown in Fig. 8 are based on Golonka (2002) and Kiessling *et al.* (2003). According to them, the South China Block, as well as Qaidam and Tarim, was located at low latitude near the equator in the southern hemisphere during the Silurian (Llandovery to Ludlow). At the same time the North China Block which does not share any of the endemic taxa presented here, was located near the middle latitudes of northern hemisphere. Thus, the South China Block was far from the North China Block during the Silurian.

The occurrences of rugose corals in the Gionyama Formation and the currently understood paleobiogeography of the Silurian suggest the possibility that 'Proto-Japan' was located at the subduction zone that developed near the edge of the South China Block in the Early Silurian. It is also suggested that there might have been a Silurian connection, via an ocean current system, between the Kurosegawa Terrane and the South China Block, Qaidam, Tarim, Kazakhstan, Tajikistan, Siberia, Baltica, North America, and Australia within a zone near the paleo-equator.

Conclusions

1. Careful taxonomic studies revealed that the Middle Member of the Gionyama Formation contains abundant rugose corals representing 18 species in 13 genera.

2. The geological age of the Middle Member of the Gionyama Formation ranges from the late Llandovery to the early Ludlow based on the rugose corals.

3. All of the rugose genera found in the Gionyama Formation also occur in the Ningqiang Formation at the northeastern part of the South China Block.

4. The rugose corals from the Gionyama Formation include both cosmopolitan genera and endemic genera. The endemic genera may indicate paleogeographic proximity between the Kurosegawa Terrane and the South China Block.

5. Cosmopolitan genera suggest that, during the Silurian, the Kurosegawa Terrane occurred in a zone parallel to the paleo-equator.

6. Paleobiogeographic interpretation based on the rugose corals from the Gionyama Formation indicates that 'Proto-Japan' probably was located at the subduction zone along the edge of the South China Block during the Silurian.

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