Early Carboniferous (Visean) brachiopods from the Hina Limestone, Okayama Prefecture, SW Japan, and their palaeobiogeographical implications

Jun-ichi TAZAWA*, Yousuke IBARAKI** and Isao NISHIKAWA***

Abstract

A brachiopod fauna consisting of 9 species in 8 genera is described from the lower part (*Endothyra* Zone) of the Hina Limestone, Okayama Prefecture, southwestern Japan. The Hina fauna includes the following species: *Leptagonia analoga*, *Dictyoclostus pinguis*, *Marginatia burlingtonensis*, *Marginatia* cf. *magna*, *Schizophoria resupinata*, *Cleiothyridina* sp., *Spirifer* cf. *liangchowensis*, *Grandispirifer* sp. and *Syringothyris* cf. *cuspidatus*. The Hina fauna has some affinities with the Early Carboniferous (Visean) brachiopod faunas of South Kitakami, Xinjiang, Kirgiz, Kazakhstan, Kuznetsk Basin, Urals and England. The palaeobiogeographical data suggest that the Akiyoshi-type reef–seamount complexes, including the Hina Limestone, were probably located at mid-latitudes of the Northern Hemisphere in the Panthalassa, near North China and Kazakhstan during Early Carboniferous (Visean).

Key words: Brachiopoda, Hina Limestone, palaeobiogeography, southwestern Japan, Visean.

Introduction

The Hina Limestone (named by Cho, 1939), distributed in the Hina area, Okayama Prefecture, southwestern Japan, is one of the Carboniferous–Permian exotic limestone–basalt blocks, being reef–seamount complexes origin, in the Akiyoshi Terrane (Kanmera et al., 1990). According to Tazawa (2009; Tazawa et al., 2009), the accretion site of the exotic

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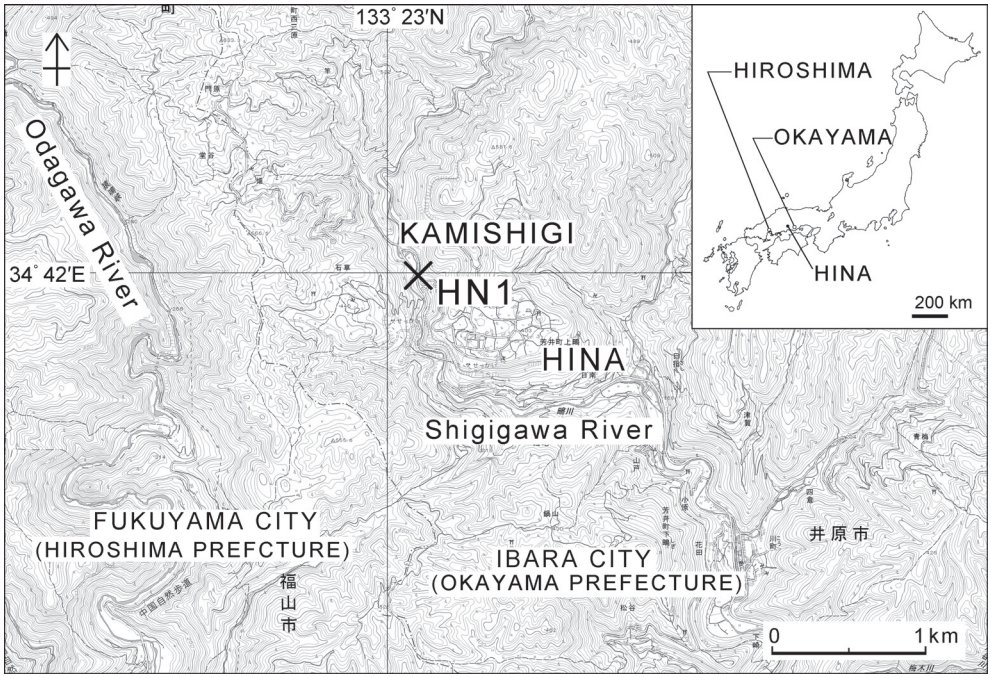


Fig. 1. Map showing the fossil locality HN1 in the Kamishigi area (using the topographical map "Jito" scale 1 : 25,000 published by the Geospatial Information Authority of Japan).

limestone–basalt blocks was probably located at subduction zone developed along the eastern margin of North China (Sino-Korea), and close to the South Kitakami and Maizuru areas, during the middle to late Permian (Capitanian–Changhsingian). However, the depositional site in Early Carboniferous is unclear, although it was supposed that the Akiyoshi-type reef–seamount complexes were probably located at the mid-Panthalassa in the Northern Hemisphere on the basis of palaeomagnetic data (Fujiwara, 1967) and brachiopod palaeobiogeography (Tazawa et al., 2005).

The present study describes brachiopod species from the lower part (*Endothyra* Zone) of the Hina Limestone, and discusses age and palaeobiogeography of the fauna. The Hina fauna is important for understanding the depositional site of the Akiyoshi-type reef–seamount complexes. In this study, I. Nishikawa prepared the brachiopod specimens; and J. Tazawa and Y. Ibaraki studied the systematics of the brachiopods. The specimens described herein are registered and housed in the Fossa Magna Museum, Itoigawa, Japan with prefix FMM.

Stratigraphy and locality

The stratigraphy of the Palaeozoic rocks in the Hina area has been studied by Cho (1939), Kobayashi (1950), Nakano (1952), Yoshimura (1961), Hase and Yokoyama (1975), Sada et al. (1978) and Sano et al. (1987). According to Hase and Yokoyama (1975) and Sada et al. (1978), the Hina Limestone is a large basalt–limestone block (2 km × 1 km, 300–450 m thick) consisting of basaltic pyroclastic rocks (about 100 m thick) and overlying massive limestone (200–350 m thick) of late Early Carboniferous (Visean) to early Late Carboniferous (Bashkirian) in age; and the limestone is subdivided into three zones, *Endothyra* Zone, *Eostaffella–Millerella* Zone and *Profusulinella* Zone, in ascending order.

The brachiopod specimens treated in the present study were collected from grey limestone of the lower part (*Endothyra* Zone) of the Hina Limestone, cropping out at locality HN1, a road-cutting at Kamishigi (about 1 km northwest of Hina), Yoshii-cho, Ihara City, Okayama Prefecture (Fig. 1).

The Hina fauna

The Hina fauna consists of the following 9 species in 8 genera: *Leptagonia analoga* (Phillips, 1836), *Dictyoclostus pinguis* (Muir-Wood, 1928), *Marginatia burlingtonensis* (Hall, 1858), *Marginatia* cf. *magna* Carter, 1968, *Schizophoria resupinata* (Martin, 1809), *Cleiothyridina* sp., *Spirifer* cf. *liangchowensis* Chao, 1929, *Grandispirifer* sp. and *Syringothyris* cf. *cuspidatus* (Sowerby, 1816). The stratigraphic and geographic distributions of the brachiopod species of the Hina fauna are summarized in Fig. 2 and Figs. 3, 4, respectively.

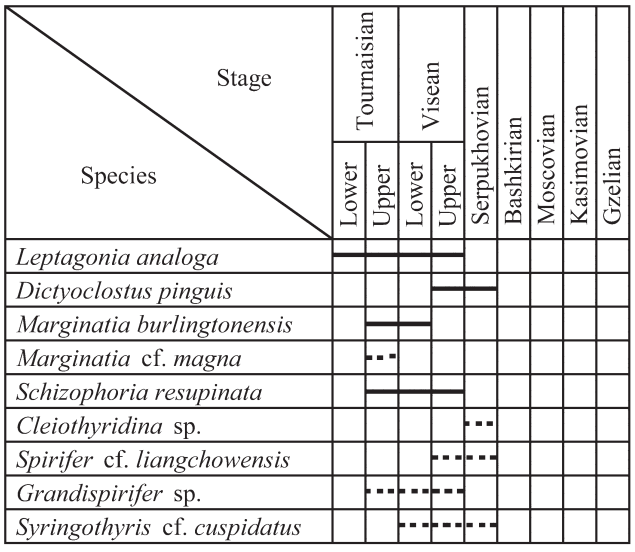


Fig. 2. Stratigraphic distribution of brachiopod species of the Hina fauna. Broken lines indicate those of the allied species.

Region		*Leptagonia analoga*	*Dictyoclostus pinguis*	*Marginatia burlingtonensis*	*Marginatia* cf. *magna*	*Schizophoria resupinata*	*Cleiothyridina* sp.	*Spirifer* cf. *liangchowensis*	*Grandispirifer* sp.	*Syringothyris* cf. *cuspidatus*
USA	1. Illinois	+		+						
	2. Iowa	+		+						
	3. Missouri	+			—					
	4. Arkansas			+						
	5. Oklahoma	+			—					
	6. Idaho					+				
	7. Utah	+								
	8. New Mexico	+								
Canada	9. Alberta	+		+					—	
N. Russia	10. Verkhoyansk Range	+				+				
	11. Taimyr Peninsula					+				—
	12. Novaya Zemlya					+				
	13. Pechora Basin	+				+				
UK	14. England	+	+			+				—
	15. Wales		+			+				
	16. Isle of Man	+								
	17. N. Ireland	+								
18. Poland			+			+				
19. Germany		+	+							
20. Belgium		+				+				
21. Spain						+				
22. Algeria									—	
W. Russia	23. Moscow Basin		+			+				—
	24. Donetz Basin	+				+				
25. Turkey		+		+						
26. Iran		+								
C. Russia	27. Urals	+		+	—	+				—
	28. Kuznetsk Basin	+		+		+				
29. Kazakhstan		+		+		+				
30. Uzbekistan						+				
31. Kirgiz			+	+					—	
NW China	32. Xinjiang	+				+			—	
	33. Gansu	+								
	34. Shaanxi					+				
N. China	35. Inner Mongolia					+				
NE Japan	36. South Kitakami Belt	+		+		+				
C. Japan	37. Kanto Mountains					+				
SW Japan	38. Akiyoshi					+	—	+		
CS China	39. Hubei	+								
	40. Guangdong	+								
	41. Guangxi	+								
SW China	42. Guizhou					+				
	43. Yunnan	+		+		+				
Australia	44. W. Australia	+								
	45. E. Australia	+								

Fig. 3. Geographic distribution of brachiopod species of the Hina fauna.

1. Age

Of the brachiopods listed above, *Leptagonia analoga* is known from the lower Tournaisian–upper Visean; *Dictyoclostus pinguis* is known from the upper Visean–Serpukhovian; *Marginatia burlingtonensis* is known from the upper Tournaisian–lower Visean; and *Schizophoria resupinata* is known from the upper Tournaisian–upper Visean.

In addition, *Marginatia* cf. *magna* resembles *Marginatia magna* Carter, 1968, from the Burlington Limestone (lower Osagean, correlated with the upper Tournaisian) of Missouri, USA; *Cleiothyridina* sp. resembles the shells, described by Yanagida (1962) as *Cleiothyridina royssii* (Léveillé, 1835) from the lower part (*Millerella* Zone, Serpukhovian) of the Akiyoshi Limestone, Akiyoshi, southwestern Japan; *Spirifer* cf. *liangchowensis* is conspecific with both *Spirifer* aff. *liangchowensis* Yanagida, 1962, from the Akiyoshi Limestone (*Millerella* Zone) of Akiyoshi and *Spirifer* aff. *besnossovae* Hase and Yokoyama, 1975, from the lower part (*Endothyra* Zone, upper Visean–Serpukhovian) of the Hina Limestone at Hina; the genus *Grandispirifer* occurs from the upper Tournaisian–upper Visean of Canada, Algeria, Kirgiz and northwestern China (Xinjiang); and *Syringothyris* cf. *cuspidatus* resembles *Syringothyris cuspidatus* (Sowerby, 1816), from the lower Visean–Serpukhovian of England and Russia (Taimyr Peninsula, Russian Platform and Urals).

In summary, the age of the Hina fauna is assigned to Visean, probably late Visean. This conclusion is slightly later than the age determination by Hase and Yokoyama (1975); in which they considered the age of the lower part (*Endothyra* Zone) of the Hina Limestone to early Visean on the basis of brachiopods, *Schizophoria* aff. *resupinata* (Martin), *Rugosochonetes* sp., *Avonia* sp., *Eomarginifera* sp., *Striatifera striata* (Fischer), *Neospirifer*? sp. and *Phricodothyris insolita* George, although the brachiopods were not described. Our conclusion is consistent with that of Tazawa et al. (1983), who considered that the age of the *Endothyra* Zone of the Akiyoshi-type basalt–limestone complexes is assigned to the late Visean–Serpukhovian, based on brachiopods, *Rhipidomella* sp. and *Delepinea* cf. *sayamensis* Yanagida from the Omi Limestone, Omi, central Japan.

2. Palaeobiogeography

Among the 9 species of the Hina fauna, three species occur in UK (England), central Russia (Urals and Kuznetsk Basin), Kazakhstan, northeastern Japan (Hikoroichi in the South Kitakami Belt) and southwestern China (Yunnan); and two species with one closely allied species occur from Canada (Alberta), Kirgiz, northwestern China (Xinjiang) and southwestern Japan (Akiyoshi in the Akiyoshi Belt). It is noteworthy that only one species occurs from South China and Australia. In terms of palaeobiogeography, the Hina fauna has some affinities with the Early Carboniferous (Visean) brachiopod faunas of South Kitakami, Xinjiang, Kirgiz, Kazakhstan, Kuznetsk Basin, Urals and England, but differs from those of South China and Australia.

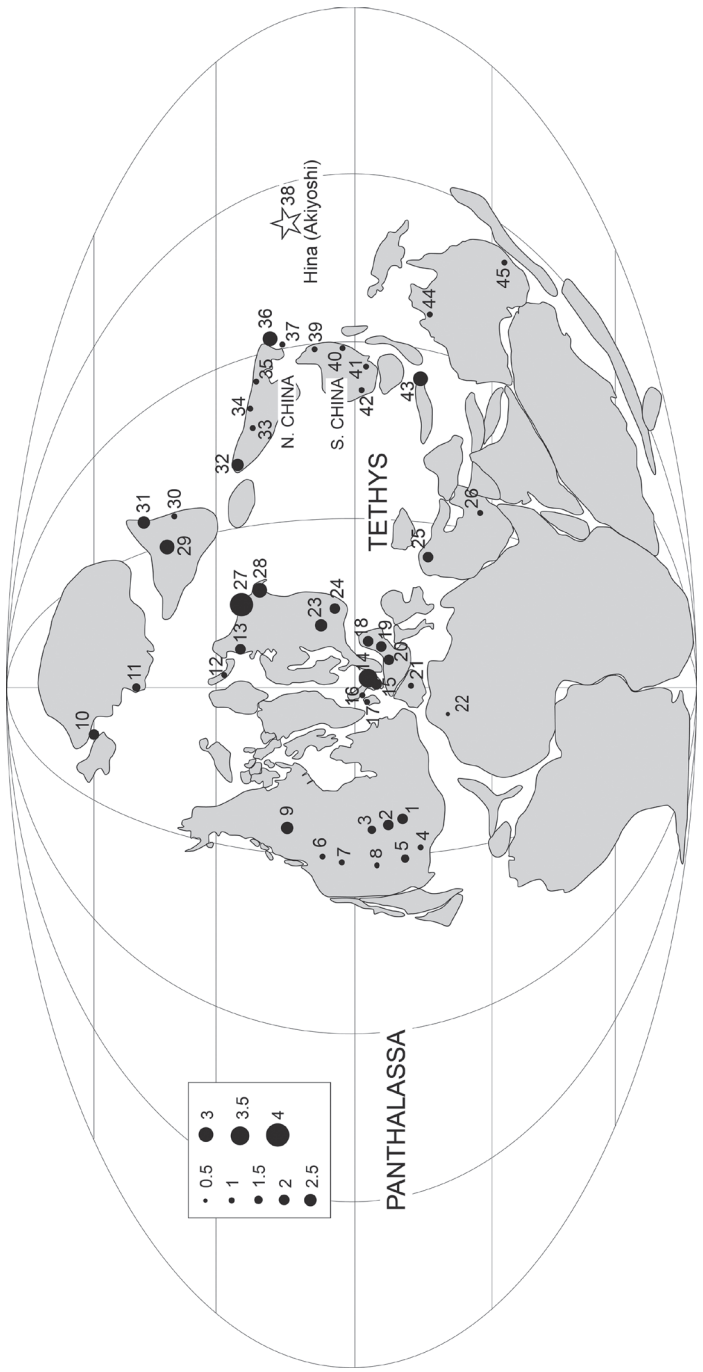


Fig. 4. Early Carboniferous (Visean) reconstruction map of the world (base map modified from Qiao and Shen, 2015). Solid circles indicate numbers of brachiopod species listed in the Hina fauna (allied species are counted 0.5; and station numbers are same as in Fig. 3).

Our results suggest that the Akiyoshi-type reef–seamount complexes, including the Hina Limestone, were probably located at mid-latitudes of the Northern Hemisphere in the Panthalassa, near North China and Kazakhstan during Early Carboniferous (Visean). This conclusion is in agreement with that of Tazawa et al. (2005); in which they emphasized that the occurrence of the brachiopod genus *Daviesiella* is restricted to the lower–upper Visean of central Japan (Omi in the Akiyoshi Terrane), northwestern China (Xinjiang), Kirgiz and UK (England and Wales).

Systematic descriptions

Order Strophomenida Öpik, 1934
Superfamily Strophomenoidea King, 1846
Family Pafinesquinidae Schuchert, 1893
Subfamily Leptaeninae Hall and Clarke, 1894
Genus *Leptagonia* M'Coy, 1844

Type species.—*Producta analoga* Phillips, 1836.

Leptagonia analoga (Phillips, 1836)
Fig. 5.5

Producta analoga Phillips, 1836, p. 116, pl. 7, fig. 10.

Strophomena rhomboidalis var. *analoga* Phillips: Davidson, 1861, p. 119, pl. 28, figs. 1–6, 9–13; Etheridge, 1872, p. 333, pl. 18, fig. 1.

Leptaena analoga (Phillips): Weller, 1914, p. 49, pl. 2, figs. 1–10; Frech, 1916, p. 237, pl. 2, figs. 2, 3d; Girty, 1920, pl. 54, fig. 3; Tolmatchoff, 1924, p. 209, 569, pl. 13, fig. 8; Girty, 1927, pl. 22, figs. 6–8; Demanet, 1934, p. 61, pl. 5, figs. 1–14, text-figs. 1–14; Branson, 1938, p. 24, pl. 5, fig. 31; Minato, 1951, p. 361, pl. 3, fig. 1; Nelson, 1961, pl. 4, fig. 26; Sokolskaya in Sarytcheva et al., 1963, p. 80, pl. 4, figs. 9–14.

Leptaena rhomboidalis Wilckens: Sommer, 1909, p. 626, pl. 29, fig. 14.

Leptagonia cf. *analoga* (Phillips): Cvancara, 1958, p. 860, pl. 110, figs. 6–13, text-figs. 3, 4.

Leptaenella analoga (Phillips): Yang, 1964, p. 61, pl. 1, fig. 5; Gretchischnikova, 1966, p. 94, pl. 1, figs. 19, 20; pl. 2, figs. 1–6; Abramov, 1970, p. 108, pl. 1, figs. 11, 12; Aisenverg and Poletaev in Aisenverg, 1971, pl. 60, figs. 2, 3; Nalivkin and Fotieva, 1973, p. 20, pl. 1, figs. 9–13.

Leptagonia analoga (Phillips): Brunton, 1968, p. 29, pl. 3, figs. 26–31; pl. 4, figs. 1–9, text-figs. 6–17; Gaetani, 1968, p. 688, pl. 47, fig. 3; Thomas, 1971, p. 30, pl. 18, figs. 1–8, text-fig. 11; Bublitschenko, 1971, p. 37, pl. 3, figs. 1–5; Brand, 1972, p. 59, pl. 8, figs. 1–6, text-figs. 1a, 3; Kalashnikov, 1974, p. 23, pl. 3, fig. 5; Litvinovich et al., 1975, p. 53, pl. 16, fig. 11;

Bublitschenko, 1976, p. 22, pl. 1, fig. 10; Yang et al., 1977, p. 316, pl. 131, fig. 2; Minato et al., 1979, pl. 15, fig. 2; Nalivkin, 1979, p. 18, pl. 3, figs. 1–3, 5, 6; Ding and Qi, 1983, p. 251, pl. 89, figs. 9, 10, 12; Zhang et al., 1983, p. 271, pl. 107, fig. 13; pl. 106, fig. 3; Tazawa et al., 1984, p. 350, pl. 67, figs. 2–4; Yang, 1984, p. 205, pl. 29, fig. 11; Xu and Yao, 1988, p. 274, pl. 67, figs. 4, 6–10; Carter, 1999, p. 96, figs. 1A–1E; Shi et al., 2005, p. 39, figs. 3A, 3E.

Leptagonia sp. Hase and Yokoyama, 1975, pl. 18, fig. 6.

Material.—One specimen, a ventral valve, FMM6187.

Description.—Shell small in size, transversely trapezoidal in outline, with greatest width at hinge; length 22 mm, width about 36 mm. Ventral valve slightly convex in umbonal region, flat to gently concave in mid to anterior portion of visceral disc, strongly geniculated, and followed by a short trail; marginal ridge around visceral disc prominent. External surface of ventral valve ornamented with numerous fine costellae and regular, slightly flexuous rugae; numbering 6–7 costellae in 2mm at about midlength, and 10 rugae in visceral disc. Interior of ventral valve not observed.

Remarks.—This specimen can be referred to *Leptagonia analoga* (Phillips, 1836), redescribed by Brunton (1968, p. 29, pl. 3, figs. 26–31; pl. 4, figs. 1–9, text-figs. 6–17) on the type specimens from the Visean of England and northern Ireland, in its flat to slightly concave ventral valve with prominent marginal ridge and produced cardinal extremities, and the external ornament consisting of numerous fine costellae and regular, slightly flexuous rugae. The Hina specimen, being smaller in size than the type specimens, may be a juvenile shell. *Leptagonia* sp. (Hase and Yokoyama, 1975, pl. 18, fig. 6), from the Hina Limestone (*Endothyra* Zone) at Hina, is deemed conspecific with *Leptagonia analoga* (Phillips).

Distribution.—Lower Carboniferous (lower Tournaisian–upper Visean): USA (Illinois, Iowa, Missouri, Oklahoma, Utah and New Mexico), Canada (Alberta), northern Russia (Verkhoyansk Range and Pechora Basin), UK (England, Isle of Man and northern Ireland), Germany, Belgium, western Russia (Donetz Basin), Turkey (Taurus Mountains), Iran (Elburz Range), central Russia (southern Urals and Kuznetsk Basin), Kazakhstan, northwestern China (Xinjiang and Gansu), northeastern Japan (South Kitakami Belt), southwestern Japan (Hina in the Akiyoshi Belt), central-southern China (Hubei, Guangdong and Guangxi), southwestern China (Yunnan), western Australia (Bonaparte Gulf Basin) and eastern Australia (Queensland and New South Wales).

Order Productida Sarytcheva and Sokolskaya, 1959

Suborder Productidina Waagen, 1883

Superfamily Productoidea Gray, 1840

Family Dictyoclostidae Stehli, 1954

Subfamily Dictyoclostinae Stehli, 1954
Genus *Dictyoclostus* Muir-Wood, 1930

Type species.—*Anomites semireticulatus* Martin, 1809.

Dictyoclostus pinguis (Muir-Wood, 1928)
Fig. 5.3

Productus pinguis Muir-Wood, 1928, p. 104, pl. 5, figs. 1–3; pl. 6, fig. 1, text-fig. 20.
Productus (Dictyoclostus) pinguis Muir-Wood: Paeckelmann, 1931, p. 278, pl. 34, fig. 2.
Dictyoclostus pinguis (Muir-Wood): Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 138, pl. 38, fig. 191; Galitzkaya, 1977, p. 96, pl. 30, figs. 3, 4; Zakowa, 1988, p. 52, pl. 4, figs. 2, 4, 5; pl. 5, figs. 1, 2.

Material.—One specimen, a ventral valve, FMM6188.

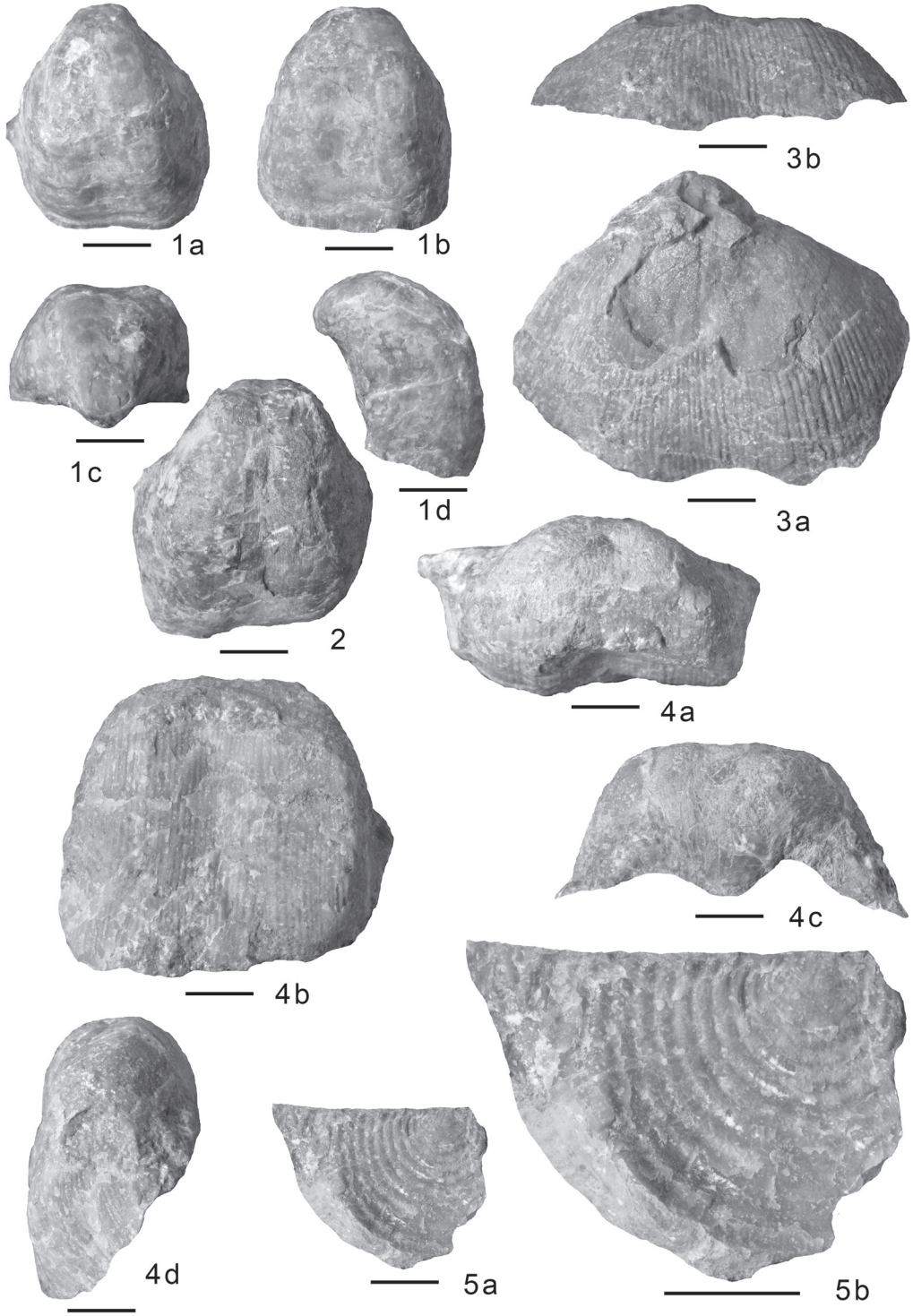
Description.—Shell large in size for genus, transversely subquadrate in outline; length about 53 mm, width more than 65 mm. Ventral valve strongly and unevenly convex in lateral profile, most convex in umbonal region, gently geniculated at anterior margin of visceral disc; sulcus broad and shallow; lateral slopes steep. External surface of ventral valve ornamented with numerous costae and few weak rugae; costae rounded, with narrower interspaces, and often bifurcated, numbering 8–9 in 10 mm near anterior margin of valve; concentric rugae few on posterior of lateral slopes. Internal structure of ventral valve not observed, except for large flabellate diductor scars.

Remarks.—This specimen is referred to *Dictyoclostus pinguis* (Muir-Wood, 1928, p. 104, pl. 5, figs. 1–3; pl. 6, fig. 1, text-fig. 20), originally described from the upper Visean of England and Wales, in the large size and the external ornament consisting of comparatively fine costae and few weak rugae on the ventral valve. The type species, *Dictyioclostus semireticulatus* (Martin, 1809), from the Visean of Derbyshire, England, is distinguished from *D. pinguis* by its smaller size and having coarser costae in the ventral valve.

Distribution.—Lower Carboniferous (upper Visean–Serpukhovian): UK (England and Wales), Poland, Germany, western Russia (Moscow Basin), Kirgiz (Tien Shan) and southwestern Japan (Hina in the Akiyoshi Belt).

Family Buxtoniidae Muir-Wood and Cooper, 1960
Subfamily Marginatiinae Waterhouse, 2002
Genus *Marginatia* Muir-Wood and Cooper, 1960

Type species.—*Productus fernglensis* Weller, 1909.


1a
1b
3b
1c
1d
3a
2
4a
4b
4c
4d
5a
5b

Marginatia burlingtonensis (Hall, 1858)
Figs. 5.1, 5.2

Productus flemingi var. *burlingtonensis* Hall, 1858, p. 598, pl. 12, fig. 3.
Productus burlingtonensis Hall: Weller, 1914, p. 104, pl. 9, figs. 1–10; Frech, 1916, p. 239, pl. 6, fig. 1; Tolmatchoff, 1924, p. 237, 575, pl. 14, figs. 8–11; Girty, 1929, p. 85, pl. 9, figs. 20–24.
Productus (Productus) burlingtonensis Hall: Nalivkin, 1937, p. 66, pl. 7, figs. 7–11.
Productus sp. Minato, 1951, p. 366, pl. 1, fig. 4.
Productus (Dictyoclostus) burlingtonensis Hall: Simorin, 1956, p. 136, pl. 9, figs. 1–3.
Marginatia burlingtonensis (Hall): Sarytcheva in Sarytcheva et al., 1963, p. 191, pl. 28, figs. 5–8, text-figs. 81, 82; Grechishnikova, 1966, p. 116, pl. 8, figs. 11–13; Litvinovich et al., 1969, p. 213, pl. 35, figs. 2–4; Nalivkin and Fotieva, 1973, p. 39, pl. 8, fig. 1; Garanj et al., 1975, p. 166, pl. 66, fig. 7; Bublitschenko, 1976, p. 50, pl. 2, fig. 12; pl. 4, fig. 6; pl. 5, figs. 4–6; pl. 6, fig. 9; Galitzkaja, 1977, p. 83, pl. 22, figs. 6–10; Nalivkin, 1979, p. 94, pl. 32, figs. 1–10; pl. 34, figs. 3, 4; Jin, 1985, p. 77, pl. 1, figs. 20–22; Carter, 1987, p. 39, pl. 9, figs. 1–8; Shi et al., 2005, p. 44, figs. 5D, 5I–5K, 5M; Tazawa, 2006, p. 132, figs. 6.1–6.8.
Dictyoclostus sp. Hase and Yokoyama, 1975, pl. 18, fig. 1.
Marginatia sp. Tazawa, 1985, p. 459, figs. 2.3–2.7; Tazawa, 1989, p. 60, pl. 1, fig. 1; Tazawa, 2002, figs. 7.1, 7.2.

Material.—Three specimens, three ventral valves, FMM6195–6197.

Remarks.—The specimens at hand are three abraded ventral valves, in which the external ornamentation are obscure, except for costellae on the trail. However, these specimens can be referred to *Marginatia burlingtonensis* (Hall, 1858), originally described by Hall (1858, p. 598, pl. 12, fig. 3) from the Burlington Limestone of Iowa and Illinois, USA, in the medium-sized (length 34 mm, width 35 mm in the largest specimen, FMM6196), strongly convex ventral valve, with narrow, deep sulcus and long trail, and ornamented with numerous fine costellae, numbering 13–14 in 5 mm at mid of trail. *Dictoclostus* sp. (Hase and Yokoyama, 1975, pl. 18, fig. 1), from the Hina Limestone (*Eostaffella–Millerella* Zone) at Hina, is deemed conspecific with the present species. *Marginatia burlingtonensis* somewhat resembles the type species, *Marginatia ferunglensis* (Weller, 1909, p. 299, pl. 12, figs. 14–17), from the Fern Glen Formation of Missouri, USA, in size and shape of the ventral valve, but differs from the latter in having deeper sulcus and lacking fluting on the ventral trail.

←**Fig. 5. 1, 2,** *Marginatia burlingtonensis* (Hall); 1a, 1b, 1c, 1d, ventral, anterior, posterior and lateral views of ventral valve, FMM6195; 2, ventral view of ventral valve, FMM6196; **3,** *Dictyoclostus pinguis* (Muir-Wood); 3a, 3b, ventral and anterior views of ventral valve, FMM6188; **4,** *Marginatia* cf. *magna* Carter; 4a, 4b, 4c, 4d, ventral, anterior, posterior and lateral views of ventral valve, FMM6189; **5,** *Leptagonia analoga* (Phillips); 5a, 5b, ventral view of ventral valve, FMM6187. Scale bars represent 1 cm.

Marginatia toriyamai Yanagida (1973a, p. 41, pl. 1, figs. 1–5; pl. 2, figs. 1–9, text-figs. 6–8), from the lowest part of the Akiyoshi Limestone in Akiyoshi, southwestern Japan, is readily distinguished from the present species by its smaller size and having shorter ventral trail. The subsequent species, *Marginatia* cf. *magna* Carter, 1968, is distinguished from the present species by its much larger size, and having thicker costae.

Distribution.—Lower Carboniferous (upper Tournaisian–lower Visean): USA (Illinois, Iowa and Arkansas), Canada (Alberta), Turkey (Taurus Mountains), central Russia (Urals and Kuznetsk Basin), Kazakhstan, Kirgiz, northeastern Japan (South Kitakami Belt), southwestern Japan (Hina in the Akiyoshi Belt) and southwestern China (Yunnan),

Marginatia cf. *magna* Carter, 1968
Fig. 5.4

Cf. *Marginatia magna* Carter, 1968, p. 1147, pl. 147, figs. 1–9.

Material.—One specimen, a ventral valve, FMM6189.

Description.—Shell large in size for genus, transversely subrectangular in outline, with greatest width at hinge; length 28 mm, width about 55 mm. Ventral valve strongly and unevenly convex in lateral profile, most convex at umbonal region, gently convex in visceral disc, strongly geniculated at anterior margin of visceral disc, and followed by a long, weakly fluted trail; sulcus broad and shallow; lateral slopes steep. External surface of trail ornamented with numerous costae and sporadically distributed spine bases, numbering 5–6 costae in 5 mm at about mid of trail; but external ornament of visceral disc abraded and not preserved.

Remarks.—This specimen most resembles *Marginatia magna* Carter, 1968, from the Burlington Limestone of Missouri, USA, in its large size and the long and slightly fluted trail on the ventral valve, but differs in having finer costellae. The type species, *Marginatia ferunglensis* (Weller, 1909), also has fluting ventral trail, but differs from the present species in its smaller size and the finer costae on the ventral valve.

Order Orthida Schuchert and Cooper, 1932
Suborder Dalmanellidina Moore, 1952
Superfmily Enteletoidea Waagen, 1884
Family Schizophoriidae Schuchert and Le Vene, 1929
Genus *Schizophoria* King, 1850

Type species.—*Conchyliolithus (Anomites) resupinatus* Martin, 1809.

Schizophoria resupinata (Martin, 1809)
Figs. 6.1, 6.2

Conchiliolithus (Anomites) resupinatus Martin, 1809, pl. 49, figs. 13, 14.

Orthis resupinata (Martin): Davidson, 1861, p. 130, pl. 29, figs. 1–4; pl. 30, figs. 1–5.

Schizophoria resupinata (Martin): Yanishevsky, 1918, p. 19, pl. 1, figs. 4, 12; pl. 4, fig. 2; pl. 6, fig. 16; Demanet, 1934, p. 45, pl. 3, figs. 1–5, text-fig. 9; Miloradovich, 1935, p. 6, pl. 1, figs. 11, 12; Bond, 1941, p. 289, pl. 21, figs. a–c, text-figs. 33, 34; Minato, 1952, p. 150, pl. 5, fig. 3; pl. 6, fig. 4; Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 29, pl. 2, fig. 12; Parkinson, 1954, p. 368, text-figs. 1, 2; Litvinovich, 1962, p. 178, pl. 1, fig. 2; Besnossova in Sarytcheva et al., 1963, p. 77, pl. 3, figs. 5–8, text-fig. 24; Ustritsky and Tschernjak, 1963, p. 69, pl. 1, figs. 13–16; Yang, 1964, p. 59, pl. 1, figs. 2, 3; Abramov, 1965, p. 35, pl. 2, fig. 3; Brunton, 1968, pl. 2, figs. 1–6; Pocock, 1968, p. 80, pl. 18, fig. 7, text-figs. 13–15; Besnossova et al., 1968, p. 53, pl. 1, figs. 11–13; Lazarev, 1969, pl. 10, figs. 1–5, text-figs. 1, 2; Litvinovich et al., 1969, p. 129, pl. 2, fig. 1; Abramov, 1970, p. 107, pl. 1, figs. 5–7; Aisenverg and Poletaev in Aisenverg, 1971, pl. 60, fig. 1; Nalivkin and Fotieva, 1973, p. 20, pl. 1, figs. 6–8; Yanagida, 1973b, p. 101, pl. 16, figs. 3–9; Kalashnikov, 1974, p. 22, pl. 3, figs. 1–3; Garanj et al., 1975, p. 155, pl. 62, fig. 2; Volgin and Kushnar, 1975, p. 23, pl. 1, figs. 3–5; Litvinovich et al., 1975, p. 52, pl. 16, fig. 7; Lazarev, 1976, pl. 2, figs. 3, 4; pl. 3, figs. 1–5, text-fig. 58; Lee and Gu, 1976, p. 229, pl. 131, figs. 7, 9–11; Martinez Chacon, 1979, p. 54, pl. 2, figs. 1–15; pl. 3, figs. 1–10, text-figs. 3–5; Minato et al., 1979, pl. 22, figs. 1, 2; Tazawa and Katayama, 1979, p. 169, pl. 11, figs. 8–14; Kalashnikov, 1980, p. 24, pl. 2, figs. 2, 3; Mori and Tazawa, 1980, text-fig. 3.3; Tazawa, 1981, p. 67, pl. 5, figs. 3–5; Tazawa et al., 1981, pl. 1, figs. 4–6; Ding and Qi, 1983, p. 245, pl. 88, fig. 7; Zhang et al., 1983, p. 265, pl. 107, figs. 1–3; Tazawa, 1984, p. 304, pl. 61, fig. 9; Abramov and Grigorjeva, 1986, p. 74, pl. 1, figs. 15–18; Yanai et al., 1988, pl. 1, figs. 9, 10; Zakowa, 1989, p. 103, pl. 1, figs. 1–5; pl. 2, figs. 1–5; pl. 3, figs. 1–4, text-figs. 2–10; Jiang, 1997, pl. 1, figs. 1, 2; Bassett and Bryant, 2006, p. 504, pl. 6, figs. 1–10; pl. 7, figs. 1–16, text-figs. 5–7; Butts, 2007, p. 55, figs. 5.3–5.10; Ibaraki et al., 2014, p. 73, figs. 4.1, 4.2.

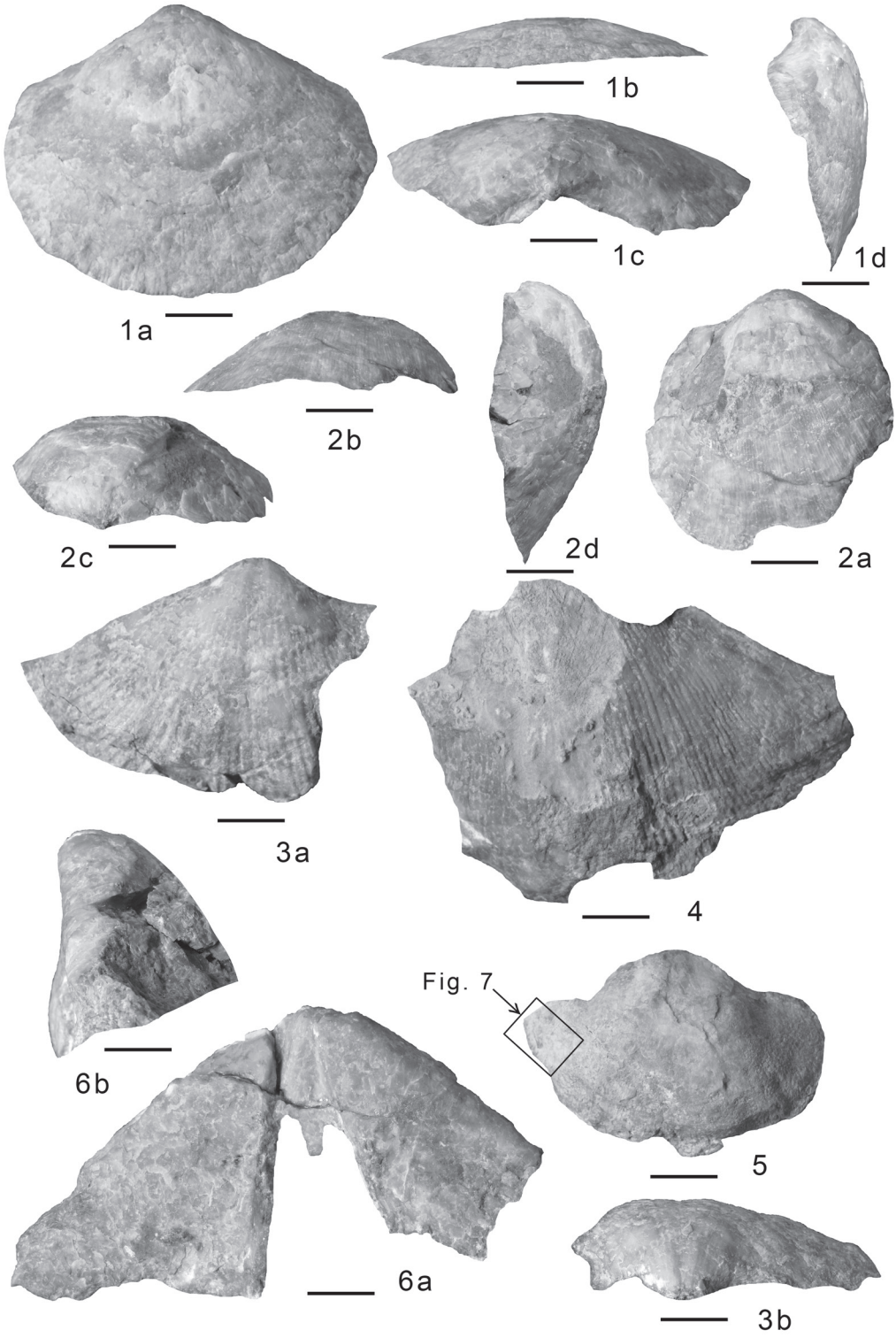
Schellwienella izirii Minato, 1951, p. 363, pl. 5, fig. 3; Minato et al., 1979, pl. 19, fig. 3.

Schizophoria aff. resupinata (Martin): Yanagida, 1962, p. 122, pl. 21, figs. 4–13, text-fig. 22; Hase and Yokoyama, 1975, pl. 16, figs. 6, 7.

Schizophoria (Schizophoria) resupinata (Martin): Sun and Baliński, 2008, p. 521, figs. 27F–27L.

Material.—Five specimens: (1) a ventral valve, FMM6190; (2) three dorsal valves, FMM6191–6193; (2) external mould of a dorsal valve, FMM6194.

Description.—Shell large in size for genus, transversely subcircular in outline; hinge much shorter than greatest width at about midlength; length 48 mm, width about 60 mm in the largest specimen (FMM6190). Ventral valve gently convex in both lateral and anterior


1a
1b
1c
1d
2a
2b
2c
2d
3a
3b
4
5
6a
6b
Fig. 7

profiles; umbo small, incurved; interarea narrow; sulcus broad and very shallow near anterior margin. Dorsal valve moderately convex in both lateral and anterior profiles; no fold. External surface of both valves ornamented with numerous fine costellae, numbering 8–9 in 5 mm at about midlength of ventral valve.

Remarks.—These specimens are referred to *Schizophoria resupinata* (Martin, 1809), redescribed by Pocock (1968, p. 80, pl. 18, fig. 7, text-figs. 13–15) from the upper Tournaisian to upper Visean of Belgium and Britain, in the large sized, wider subcircular and slightly convex ventral valve, and external ornamentation of numerous fine costellae. *Schizophoria* aff. *resupinata* (Martin, 1809), described by Yanagida (1962, p. 122, pl. 21, figs. 4–13, text-fig. 22) from the Akiyoshi Limestone (*Millerella* Zone) of Akiyoshi, southwestern Japan, and also figured by Hase and Yokoyama (1975, pl. 16, figs. 6, 7) from the Hina Limestone at Hina, is conspecific with the present species.

Distribution.—Lower Carboniferous (upper Tournaisian–upper Visean): USA (Idaho), northern Russia (Verkhoyansk Range, Taimyr Peninsula, Novaya Zemlya and Pechora Basin), UK (England and Wales), Poland, Belgium, Spain, western Russia (Moscow Basin and Donetz Basin), central Russia (southern Urals and Kuznetsk Basin), Kazakhstan, Uzbekistan (Fergana), northwestern China (Xinjiang and Shaanxi), northern China (Inner Mongolia), northeastern Japan (South Kitakami Belt), central Japan (Kanto Mountains), southwestern Japan (Hina and Akiyoshi in the Akiyoshi Belt) and southwestern China (Guizhou and Yunnan).

Order Athyridida Boucot, Johnson and Staton, 1964
Suborder Athyrididina Boucot, Johnson and Staton, 1964
Superfamily Athyridoidea Davidson, 1881
Family Athyrididae Davidson, 1881
Subfamily Cleiothyridinae Alvarez, Rong and Boucot, 1998
Genus *Cleiothyridina* Buckman, 1906

Type species.—*Atrypa pectinifera* Sowerby, 1840.

Cleiothyridina sp.
Figs. 6.5, 7

←**Fig. 6. 1, 2,** *Schizophoria resupinata* (Martin); 1a, 1b, 1c, 1d, ventral, anterior, posterior and lateral views of ventral valve, FMM6190; 2a, 2b, 2c, 2d, dorsal, anterior, posterior and lateral views of dorsal valve, FMM6191; **3,** *Spirifer* cf. *liangchowensis* Chao; 3a, 3b, ventral and posterior views of ventral valve, FMM6185; **4,** *Grandispirifer* sp., dorsal view of dorsal valve, FMM6199; **5,** *Cleiothyridina* sp., ventral view of ventral valve, FMM6200; **6,** *Syringothyris* cf. *cuspidatus* (Sowerby); 6a, 6b, posterior and lateral views of ventral interarea, FMM6198. Scale bars represent 1 cm.

Material.—One specimen, a ventral valve, FMM6200.

Remarks.—This specimen is safely assigned to the genus *Cleiothyridina* by its medium-sized (length 28 mm, width 43 mm), transversely elliptical and moderately convex ventral valve with very shallow sulcus, and ornamented by slightly irregular concentric lamellae bearing numerous fine flattened spines. The Hina specimen somewhat resembles the shells, described by Yanagida (1962, p. 103, pl. 17, figs. 2–11, text-figs. 10–15) as *Cleiothyridina royssii* (Léveillé, 1835) from the Akiyoshi Limestone (*Millerella* Zone) of Akiyoshi, southwestern Japan, in its size and shape of the ventral valve. However, accurate comparison is difficult for the poorly preserved specimen.

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Spiriferidae King, 1846
Subfamily Spiriferinae King, 1846
Genus *Spirifer* Sowerby, 1816

Type species.—*Conchyliolithus (Avonia) striatus* Martin, 1793.

Spirifer cf. *liangchowensis* Chao, 1929
Fig. 6.3

Spirifer aff. *liangchowensis* Chao: Yanagida, 1962, p. 96, pl. 15, fig. 7, text-figs. 5, 6.
Spirifer aff. *besnossovae* Abramov: Hase and Yokoyama, 1975, pl. 16, figs. 1–5.

Material.—Two specimens, two ventral valves, FMM6185, 6186.

Description.—Shell medium in size for genus, transversely subelliptical in outline, widest at about midlength; length about 40 mm, width about 66 mm in the better preserved specimen (FMM6185). Ventral valve moderately convex in lateral profile, most convex at umbonal region; sulcus broad and shallow, not clearly demarcated from lateral slopes. External surface of ventral valve ornamented with numerous simple rounded costae and few irregular, weak concentric rugae; costellae often bifurcated in anterior portion, numbering 7–8 in 10 mm at about midlength.

Remarks.—The specimens from Hina resembles *Spirifer liangchowensis* Chao (1929, p. 6, pl. 1, figs. 1–7, text-fig. 1), from the Chouniugou Formation of Gansu, northwestern China, in size, shape and external ornament of the ventral valve. Both of *Spirifer* aff. *liangchowensis* Chao, 1929, described by Yanagida (1962, p. 96, pl. 15, fig. 7, text-figs. 5, 6) from the Akiyochi Limestone (*Millerella* Zone) at the Uzura Quarry, Akiyoshi, southwestern Japan and *Spirifer*

aff. *besnossovae* Abramov, 1965, figured by Hase and Yokoyama (1975, pl. 16, figs. 1–5) from the Hina Limestone (*Endothyra* Zone) at Hina, are deemed conspecific with the present species. *Spirifer besnossovae* Abramov (1965, p. 50, pl. 6, figs. 1–4; pl. 7, fig. 1), from the lower Visean of Sette Daban, southern Verkhoyansk Range, northeastern Russia differs from the present species by its much larger size.

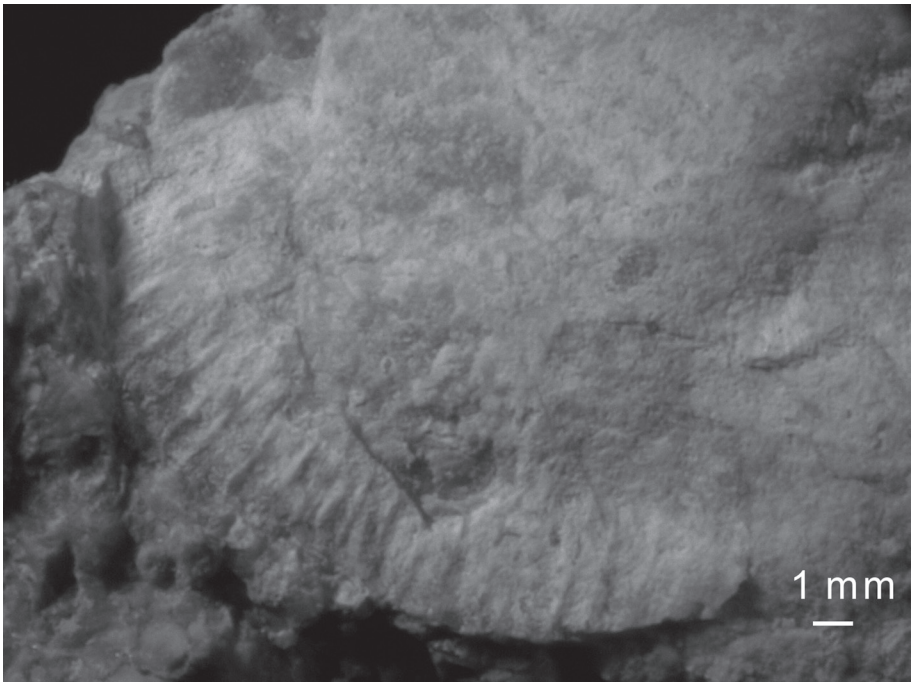


Fig. 7. Microornament of *Cleiothyridina* sp., enlarged external surface of ventral valve (FMM6200, fig. 6.5), showing concentric lamella bearing numerous flattened spines.

Genus *Grandispirifer* Yang, 1959

Type species.—*Grandispirifer mylkensis* Yang, 1959.

Grandispirifer sp.
Fig. 6.4

Material.—One specimen, a dorsal valve, FMM6199.

Remarks.—This specimen is safely assigned to the genus *Grandispirifer* by its large, strongly transverse dorsal valve (length about 55 mm, width more than 68 mm, probably about 100 mm) with alate cardinal extremities and ornamented by numerous costae on both fold and lateral slopes. The stratigraphic range of *Grandispirifer* is considered to be the

upper Tournaisian–upper Visean (Yang, 1959; Legrand-Blain, 1986). The Hina species is close to the type species, *Grandispirifer mylkensis* Yang (1959), originally described by Yang (1959, p. 118, pl. 1, figs. 1, 2; pl. 2, figs. 1–3), from the lower Visean of Mt. Borochoro, Xinjiang, northwestern China, in size and shape of the dorsal valve, but differs in having finer costae (numbering 6–7 in 5 mm at mid of lateral slopes).

Order Spiriferinida Ivanova, 1972
Suborder Spiriferinidina Ivanova, 1972
Superfamily Syringothyridoidea Fredericks, 1926
Family Syringothyrididae Fredericks, 1926
Genus *Syringothyris* Winchell, 1863

Type species.—*Syringothyris typa* Winchell, 1863.

Syringothyris cf. *cuspidatus* (Sowerby, 1816)
Fig. 6.6

Syringothyris sp. Hase and Yokoyama, 1975, pl. 17, fig. 1.

Material.—One specimen, a fragment (posterior portion) of ventral valve, FMM6198.

Remarks.—This specimen is safely assigned to the genus *Syringothyris* by its large, triangular, high and flattened interarea (width 74 mm, height 42 mm) and a distinct syrinx in the ventral valve. The Hina specimen is identical with *Syringothyris* sp., figured by Hase and Yokoyama (1975, pl. 17, fig. 1) from the Hina Limestone (*Endothyra* Zone) at Hina, in size and shape of the ventral interarea. The Hina species, both the present specimen and the Hase and Yokoyama's specimen, resembles *Syringothyris cuspidatus* (Sowerby, 1816), redescribed by Muir-Wood (1951, p. 112, pl. 4, fig. 1) from the upper Visean of Derbyshire, England, in size and shape of the ventral valve, especially, in having high, triangular ventral interarea; the latter is known also from the lower (?) Visean–Serphkovian of Russia (Taimyr Peninsula, Russian Platform and western Urals) (Dedok and Tschernjak, 1960; Garanj et al., 1975). *Syringothyris altaica* Tolmatchoff (1924, p. 162, 555, pl. 8, figs. 9–11; pl. 9, fig. 1), from the upper Tournaisian of the Kuznetsk Basin, central Russia, is also a large-sized *Syringothyris*, with a high, flat ventral interarea. However, accurate comparison is difficult for the poorly preserved specimen.

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