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PENNSYLVANIAN BRACHIOPODS FROM THE GEUMCHEON-JANGSEONG FORMATION, PYEONGAN SUPERGROUP, TAEBAEKSAN BASIN, KOREA

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ABSTRACT—We provide the first detailed systematic taxonomy and paleoecological investigation of late Paleozoic brachiopod faunas from Korea. Specifically, we focus on the brachiopods from the Geumcheon-Jangseong Formation, the lower part of the Pyeongan Supergroup in the Taebaeksan Basin. The formation yields a variety of marine invertebrate fossils, including brachiopods, molluscs, echinoderms, corals, fusulinids, and conodonts. Diverse brachiopods are described from six siliciclastic horizons of the formation at three localities, including 23 species belonging to 20 genera with two new species: *Rhipidomella parva* n. sp. and *Stenoscisma wooi* n. sp. Three brachiopod assemblages of the late Moscovian (Pennsylvanian) age are recognized based on their species compositions and stratigraphic distributions, namely the *Choristites*, *Rhipidomella*, and *Hustedia* assemblages. The brachiopod faunal composition varies within each assemblage as well as between the Assemblages, most likely reflecting local paleoenvironmental and hence paleoecological differences. The *Choristites* Assemblage includes relatively large brachiopods represented by *Derbyia*, *Choristites*, and *Stenoscisma* and may have inhabited open marine to partly restricted marine environments, whereas the *Rhipidomella* and *Hustedia* Assemblages consist of a small number of small-sized brachiopods living in lagoonal environments. The *Choristites* Assemblage shows a close affinity with Moscovian brachiopod assemblages in the eastern Paleo-Tethys regions, especially the *Brachythyrina lata–Choristites yanghukouensis–Echinoconchus elegans* Assemblage of North China, whereas the *Rhipidomella* and *Hustedia* assemblages both exhibit strong endemism.

INTRODUCTION

THE PYEONGAN Supergroup (late Paleozoic) in the Taebaeksan Basin comprises largely a siliciclastic succession (ca. 1,700 m thick) deposited in marginal marine and nonmarine environments (Cheong, 1969; Chough et al., 2000; Lee and Chough, 2006a, 2006b). It has been studied intensively during the last 40 years because it contains economically important coal measures. Nevertheless, detailed stratigraphy of the Pyeongan Supergroup has not yet been clearly established, due to the structural complexity and lack of detailed lithologic descriptions. Lee and Chough (2006a) redefined the lithostratigraphy of the Pyeongan Supergroup in the Taebaek area and suggested a depositional model based on sedimentological analysis.

The lower part of the Pyeongan Supergroup in the Taebaeksan Basin yields diverse marine invertebrate fossils including brachiopods, molluscs, echinoderms, corals, fusulinids, and conodonts (Cheong, 1973; Yang et al., 1984). To date, paleontological studies of the Pyeongan Supergroup have been focused mainly on microfossils such as fusulinids and conodonts which have proved critical for age-determination and biostratigraphic correlation, while the macroinvertebrate fossils of the Pyeongan Supergroup have not been studied in detail despite their potential significance for not only constraining age determination but also for paleoecological, paleoenvironmental, and regional paleogeographical reconstructions.

The present paper is therefore aimed to provide the first detailed systematic study of the brachiopod faunas from the Geumcheon-Jangseong Formation of the Pyeongan Supergroup in the Taebaek area. The age of the brachiopod faunas is determined by fusulinids and conodonts in the limestone interlayers. The taxonomic and biostratigraphic data generated from this study are then used for elucidating the faunal changes associated with environmental fluctuations. Additionally, we also provide a brief discussion on the paleobiogeographical implications of the studied brachiopod faunas as a whole.

STRATIGRAPHY AND LOCALITY

The Taebaeksan Basin occupies the central-eastern part of Korean Peninsula (Fig. 1). In this basin, the Upper Paleozoic succession is widely distributed and consists mainly of conglomerate, sandstone, purple siltstone, and gray/black shale with coal and limestone beds. The succession rests unconformably on the carbonate sequence of the Joseon Supergroup (Cambro-Ordovician) and is unconformably overlain by the Mesozoic sequence (Chough et al., 2000). In the Taebaek area, the succession is mainly exposed along the axis of the Baekunsan Syncline, which is a large-scale north-south compressional structure that was folded and offset by north-northeast-to-south-southwest-running strike-slip faults (Fig. 1; Lee and Chough, 2006a).

The Upper Paleozoic succession in the Taebaek area was initially subdivided into the Hongjeom, Sadong, Gobangsan, and Nogam series, which followed the scheme of the Pyeongan System of the Pyeongnam Basin in North Korea (Shiraki, 1930). Cheong (1969) suggested a new stratigraphic scheme in which he subdivided the succession in the Taebaek area into three groups and seven formations based on differences in both fossil content and lithology (Fig. 2). As the scheme was widely used by subsequent researchers, the whole Upper Paleozoic succession in the Taebaeksan Basin was naturally named the Pyeongan Supergroup. More recently, Lee and Chough (2006a) refined the lithostratigraphy of the Upper Paleozoic sequence and proposed that only the Hwangji Group be used for the sequence in the Taebaek area instead of the division into three groups, as Cheong (1969) suggested (Fig. 2). This refined stratigraphic scheme is followed here.

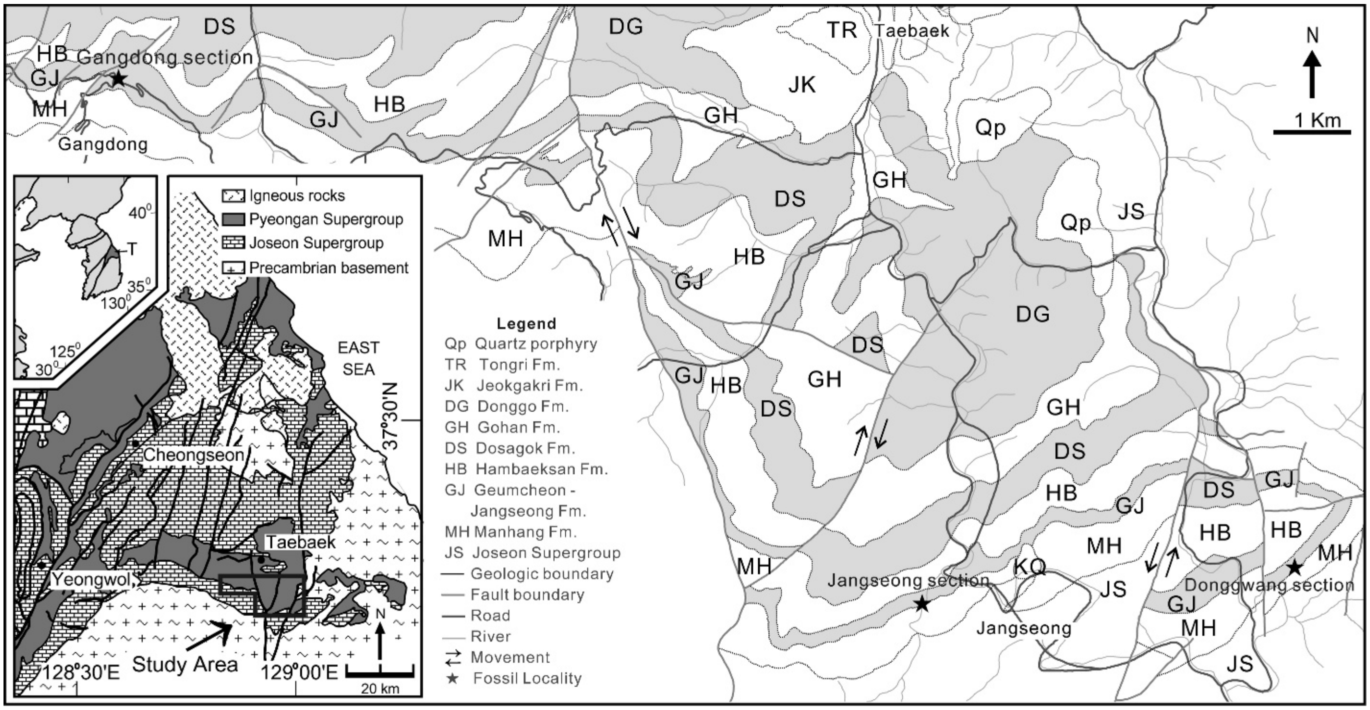


FIGURE 1—Geologic map of the Taebaek area in South Korea and three fossil localities (modified after Lee and Chough, 2006a).

The Manhang Formation, the lowermost unit of the Hwangji Group is comprised of reddish/greenish gray sandstone, purple siltstone/mudstone, white to light gray limestone, and pebbly conglomerate. The limestone lenses in the upper part of the formation contain marine fossils such as fusulinids, conodonts, and bryozoans (Cheong, 1973; Park and Sun, 2001; Lee and Chough, 2006b). The Geumcheon-Jangseong Formation consists of dark gray sandstone, black

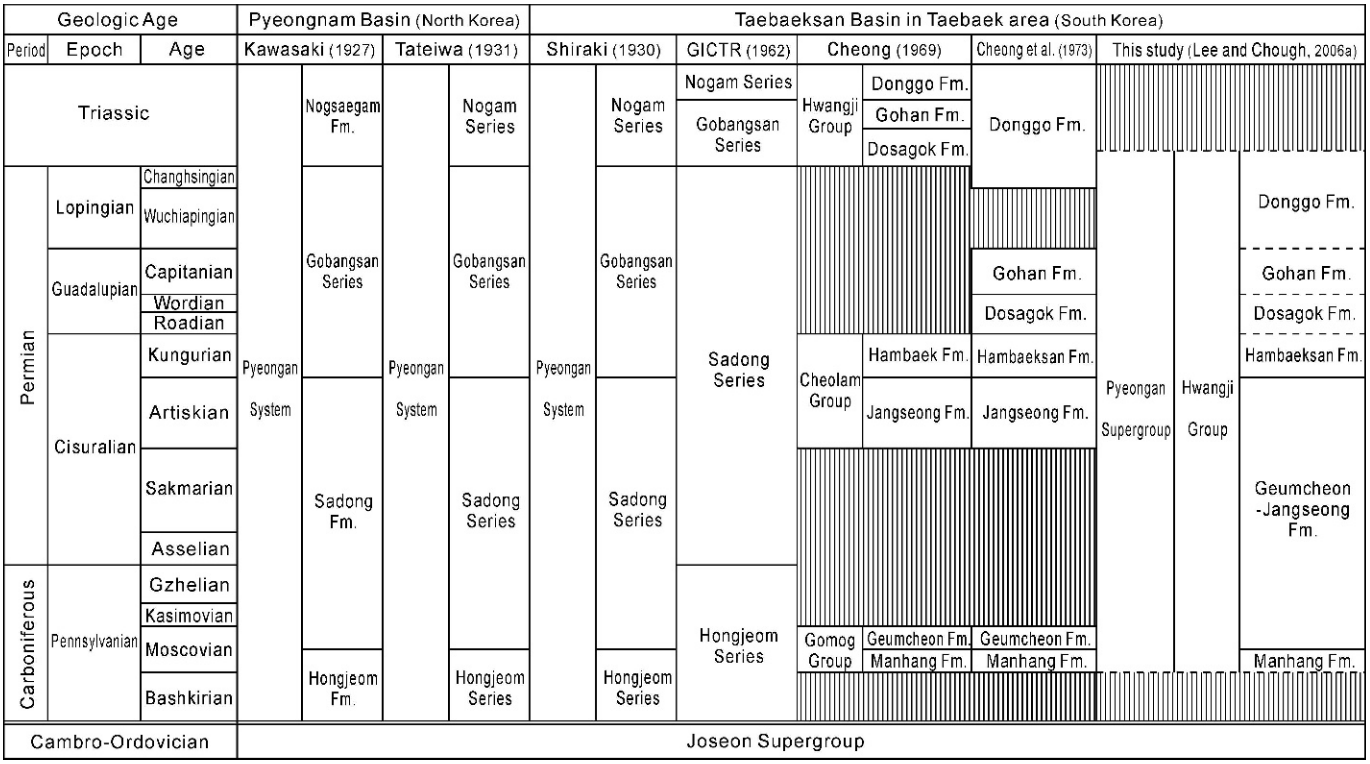


FIGURE 2—History of the lithostratigraphic nomenclature. The height of blank space for each Age represents the relative geologic time interval according to the International Geologic Time Scale (Gradstein et al., 2004). Double lines, unconformity; dashed lines, uncertain age; vertical lined areas, time gap.

shale, gray limestone, and coal. Marine invertebrates including fusulinids, conodonts, crinoids, molluscs, brachiopods, and corals were found in bioturbated limestone and siltstone beds. Fusulinids and conodonts from limestone beds in the Manhang and the Geumcheon-Jangseong formations represent a Moscovian age, whereas black shale beds in the upper part of the Geumcheon-Jangseong Formation contain numerous plant fossils, indicating a Cisuralian age (Cheong, 1969, 1973; Chun, 1985, 1987; Park and Sun, 2001). The overlying Hambaeksan Formation is composed predominantly of milky white coarse-grained sandstone to conglomerate with gray shale. The Dosagok Formation is comprised of pebble-bearing sandstone and purple shale. The Gohan Formation consists of gray to greenish gray sandstone and siltstone with coaly shale. Although the Hambaeksan, Dosagok, and Gohan formations yield some plant fossils of Permian age (Cheong et al., 1973; Cheong, 1981; Chun, 1985, 1987), it is difficult to judge the precise age of these formations due to the long stratigraphical ranges of the plant fossils and the lack of other fossils and radiometric data. The uppermost Donggo Formation consists mainly of cross-stratified conglomerate, pebbly sandstone, and purple fine sandstone and unconformably underlies the Mesozoic Jeokgakri Formation (Chough et al., 2000).

Three well-exposed outcrop sections representing the lower part of the Hwangji Group were examined along the roadcuts in the southeastern part of the Baekunsan syncline. All specimens for this study were obtained from the Geumcheon-Jangseong Formation exposed at these localities: i.e., the Gangdong section (N37°09′43″, E128°52′53″) c. 13 km northwest of Jangseong town; the Jangseong section (N37°06′01″, E129°00′07″) c. 1 km west of Jangseong town; and the Donggwang section (N37°06′12″, E129°03′15″) c. 4 km east of Jangseong town (Fig. 1).

The Gangdong section is about 90 m thick and occurs along a mountain trail in the Gurae area. It represents the lower part of the Geumcheon-Jangseong Formation. The section is comprised of black shale, dark gray siltstone, black sandstone, and thick limestone beds with thin-bedded or nodular chert layers, and it can be divided into three parts. The lower part of the section is severely deformed and has two fossil-bearing layers (SA, SB) from which Choi (1988) and Chang (1991) reported invertebrate fossils. These layers are, however, excluded from the present study because of the absence of brachiopods. Two shale layers (SF, SD) in the middle part contain abundant brachiopods, bivalves, and crinoid stems (Fig. 3.1). The SE layer in the uppermost part of the section, composed of weathered fine-grained sandstone, yields relatively diverse brachiopod fauna with bryozoans and crinoids stems (Fig. 3.1). The Gangdong section is characterized by thick limestone layers (ca. each 1–2 m-thick), whereas the limestone layers are generally thin and laterally discontinuous in the other two sections.

The Jangseong section is located along the road to the Geumcheon village. This section of about 150 m thickness represents the uppermost part of the Manhang Formation to the upper part of the Geumcheon-Jangseong Formation. The lower part of the section, representing the uppermost part of the Manhang Formation is comprised of gray/reddish sandstone, purple siltstone, mudstone, and conglomerate with three thin lenses of white limestone. The limestone lenses are grainstones composed of bioclasts (brachiopods, foraminifera, and algal remains) and siliciclastic clasts. The middle part, with fossil bearing layers, consists mainly of cross-stratified conglomerate, sandstone, and black shale. Fossil-yielding layers (MGL and MG) are close to the boundary between the Manhang and Geumcheon-Jangseong formations (Fig. 3.2) and include brachiopods, bivalves, corals, trilobites, and crinoids. The upper layer (MG) was already reported as yielding diverse invertebrate fossils by Yang et al. (1984) and Yun and Yang (1997). The dark gray shale layer in the middle part of the section yields chamosite nodules and plant fossils, correlated with the chamosite nodule-bearing layer of the Donggwang section. The upper part of the section is a rhythmic sequence consisting of multiple couplets of fining-upward units from cross-stratified conglomerate to black sandstone and black shale. The rhythmic nature of rock beds and their lithologies can also be well correlated to the upper part of the Donggwang section. The composite thickness of the Geumcheon-Jangseong Formation at the section is about 100 m, although the precise thickness is indeterminate due to faults and covered intervals. The Geumcheon-Jangseong Formation conformably underlies the Hambaeksan Formation in the Jangseong section.

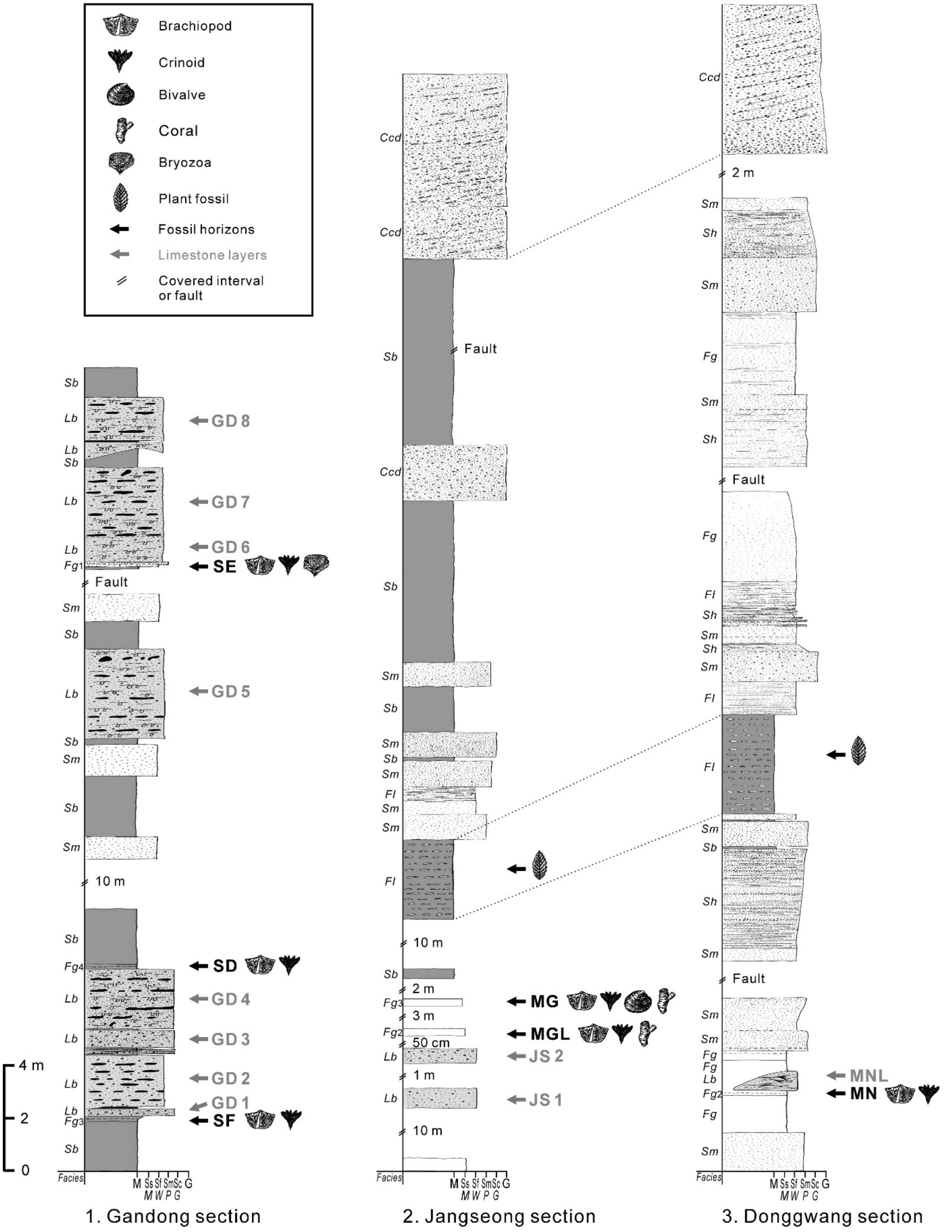
The Donggwang section, about 200 m in thickness including covered intervals, occurs along a mountain slope near the Gumunso area and represents most of the Geumcheon-Jangseong Formation. The lower part of the section consists mainly of gray siltstone, greenish gray sandstone, and discontinuous limestone. Only a single brachiopod-bearing layer (MN) was found at this section (Fig. 3.3). This layer consists of dark gray very fine-grained sandstone and yields a relatively diverse brachiopod assemblage and abundant crinoid stems. The overlying lime wackestone contains fusulinids and crinoid stems. A gray shale bed (4 m-thick) in the middle part of the section is characterized by Fe-rich chamosite nodules with plant fossils. The upper part of the section is a repetitive succession of fining-upward units consisting of cross-stratified granulite, fine- to coarse-grained black massive sandstone, and black shale. The stratigraphic portion of the black shale bed is much lower than those of other two sections. Plant fossils are common in black to gray shale layers.

SYSTEMATIC PALEONTOLOGY

All the described materials are registered with and housed in Museum Victoria, Melbourne, Australia, with prefix NMV P followed by a six-digit number. The classification of Brachiopoda adopted herein follows Brunton et al. (2000) for Productida, Williams et al. (2000) for Orthotetida, Williams and Harper (2000) for Orthida, Savage et al. (2002) for Rhynchonellida, Alvarez and Rong (2002) for Athyridida, Carter et al. (2006) for Spiriferida, and Carter and Johnson (2006) for Spiriferinida.

Phylum BRACHIOPODA Duméril, 1806
Subphylum RHYNCHONELLIFORMEA Williams et al., 1996
Class STROPHOMENATA Williams et al., 1996
Order PRODUCTIDA Sarytcheva and Sokolskaya, 1959
Suborder PRODUCTIDINA Waagen, 1883
Superfamily PRODUCTOIDEA Gray, 1840
Family PRODUCTELLIDAE Schuchert *in* Schuchert and LeVene, 1929
Subfamily MARGINIFERINAE Stehli, 1954
Tribe BREILEENIINI Brunton *in* Brunton and Lazarev, 1997
Genus BREILEENIA Brunton *in* Brunton and Lazarev, 1997
BREILEENIA RADIATA Brunton *in* Brunton and Lazarev, 1997
Figures 4.1–4.5

Breileenia radiata BRUNTON *in* BRUNTON AND LAZAREV, 1997, p. 389, figs. 5.12–5.21.



1. Gandong section

2. Jangseong section

3. Donggwang section

FIGURE 3—Stratigraphic columns of the three studied sections showing fossil horizons. M, mudstone; Ss, siltstone; Sf, fine sandstone; Sm, medium sandstone; Sc, coarse sandstone; G, granulite; *M*, lime-mudstone; *W*, wackestone; *P*, packstone; *G*, grainstone. Sedimentary facies are explained in Table 1.

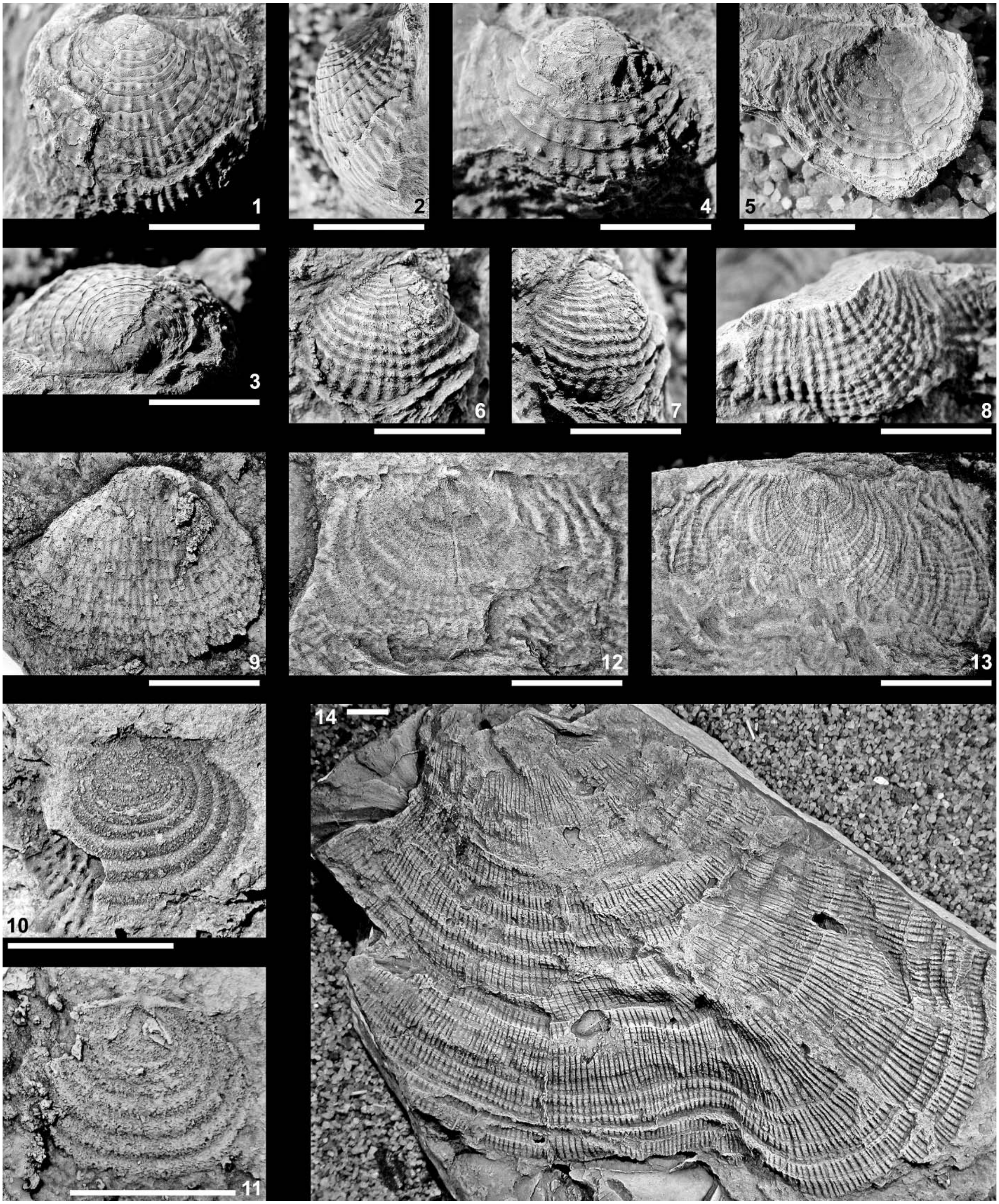


FIGURE 4—*1–5*, *Breileenia radiata* Brunton *in* Brunton and Lazarev, 1997, all ×4: *1–3*, NMV P309801, ventral, lateral, and posterior views of an incomplete ventral valve; *4*, NMV P309803, ventral view of an incomplete ventral valve; *5*, NMV P309802, dorsal view of an incomplete dorsal valve; *6–8*, *Reticulatia*? sp.: *6–7*, NMV P309804, ventral and lateral views of an incomplete ventral valve, ×4; *8*, NMV P309805, ventral view of an incomplete ventral valve, ×4; *9*, *Buxtonia* sp., NMV P309806, latex cast of an incomplete dorsal external mold, ×4; *10–11*, *Calliprotonia* sp., ×6: *10*, NMV P309807, dorsal view of external mold of a dorsal valve; *11*, NMV P309808, latex cast of an incomplete dorsal internal mold; *12–13*, *Linoproductus* sp., ×4: *12*, NMV P309809, internal mold of a dorsal valve; *13*, NMV P309810, dorsal view of a dorsal external mold; *14*, *Orthotetes* sp., NMV P309811, internal mold of a shell fragment, ×1.5. Scale bars are 5 mm.

Description.—Shell about 10 mm in width, and about 11 mm in length; greatest width at midvalve; outline subrounded; profile moderately concavoconvex with shallow corpus cavity. Ventral valve moderately curved in lateral view; beak not preserved; umbo slightly swollen with gentle umbonal slopes; ears flat, narrow, and short. Dorsal disc subcircular, slightly less curved than ventral valve. Shell surface of ventral valve ornamented with ribs; ribs originating about 3 mm from umbo, interrupted by slightly lamellose concentric bands, weak on posterior part but strongly developed anteriorly, increasing anteriorly by intercalation, about seven ribs per 5 mm on anterior part of valve; interspaces generally narrower than ribs on anterior part of valve; spine bases on rib crests, dispersed randomly on valve but decreasing anteriorly, not swollen; no sulcus. Dorsal valve exterior also ornamented with ribs bearing small spine bases; ribs weaker than those of ventral valve; lamellose concentric bands emerging from umbonal region, band intervals increasing anteriorly, about seven bands from umbo to 5 mm anterior part.

Material.—An incomplete specimen (NMV P309801), a fragmentary dorsal valve (NMV P309802), and a ventral valve (NMV P309803).

Occurrence.—Mississippian (late Visean), England; Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—The present specimens agree well with *Breileenia radiata* Brunton (*in* Brunton and Lazarev, 1997) from the late Visean strata of England except for the comparatively small size of the shell. The present specimens are also similar to *B. davidsoni* (Jarosz), figured by Brunton and Lazarev (1997, p. 389, figs. 5.1–5.11), which however has well-developed ribs with swollen spine bases in the posterior part of the valves. *Hexiproductus echidniformis* (Grabau *in* Chao), figured by Shi et al. (2008, p. 290, figs. 6A–6D), from North China is also comparable with the present species in size and ventral ornamentation. However, Shi et al. (2008) differentiated the genus *Hexiproductus* Chen and Shi (*in* Shi et al., 2008, p. 289), from *Breileenia* by a more transverse outline as well as by the absence of dorsal spines. *Fimbrinia plummeri* (King, 1938, p. 276) from the late Pennsylvanian strata of Texas (USA) is close to the present materials in its small shell size with a subrounded outline and the presence of small spines on both valves, but the former lacks ribs, whereas ribs are well developed on the corpus of *Breileenia radiata*.

Brunton and Lazarev (1997) limited the stratigraphic range of *Breileenia* from late Tournaisian to Serpukhovian, although they mentioned that the genus also possibly occurs in younger rocks of China. The documentation of *Breileenia* in this study not only confirms the occurrence of the genus in the Sino-Korean block but also extends its stratigraphical range to Moscovian.

Family PRODUCTIDAE Gray, 1840
Subfamily DICTYOCLOSTINAE Stehli, 1954
Genus RETICULATIA Muir-Wood and Cooper, 1960
RETICULATIA? sp.
Figure 4.6–4.8

Description.—Shell small for genus, ranging from 7 to 14 mm in width. Ventral valve gently convex; umbo slightly swollen with maximum convexity; anterior margin rounded; sulcus broad but weak, originating from umbonal region; ears partly preserved. Shell surface ornamented with numerous costae and rugae; costae shallow, rounded, and distinct anteriorly, starting from umbonal region, increasing anteriorly by bifurcation on flanks and anterior part of valve; rugae numerous, strong, interrupting costellation on posterior part of valve, weak anteriorly, making wrinkles on ears; no spines.

Material.—Two ventral valves (NMV P309804, 309805).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—These specimens do not show ginglymus, a characteristic of *Reticulatia* Muir-Wood and Cooper, 1960, because their posterior margins are not preserved. However, their shell ornamentation, such as numerous closely placed rugae on the posterior part of the valve, indicates an affinity to this genus. *Reticulatia taiyuanfuensis* (Grabau *in* Chao, 1927, p. 30, pl. 1, fig. 10; pl. 2, figs. 1–12; pl. 8, fig. 16) from the Carboniferous strata of North China is the species most nearly comparable with the present specimens, considering its small size and shell ornament. However, the poor preservation of these specimens precludes a definite assessment at both the specific and generic levels.

Subfamily BUXTONIINAE Muir-Wood and Cooper, 1960
Tribe BUXTONIINI Muir-Wood and Cooper, 1960
Genus BUXTONIA Thomas, 1914
BUXTONIA sp.
Figure 4.9

Description.—Shell surface of dorsal valve ornamented with concentric growth lamellae and nodose costae; growth lamellae irregular in interval and somewhat narrower on marginal part of valve, lamellae near anterior margin bearing small prone spine bases; costae relatively irregular, fine, shallow, and interrupted by growth lamellae, in number about nine per 3 mm on anterior part of the valve; crests of the costae slightly rounded to flat and troughs very narrow; small pits dispersed irregularly.

Material.—An incomplete dorsal external mold (NMV P309806).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—The ornamentation of this specimen, especially the nodose costae, is similar to that of *Buxtonia* Thomas, 1914. The present specimen closely resembles a specimen figured as *B. scabricula* (Martin) by Sarytcheva and Sokolskaya (1952, p. 101, pl. 16, fig. 114) from the Moscow Basin of Russia in the ornamentation of the dorsal valve, which is composed of weak costae and growth lamellae. Comparable species from China, *B. rugulosa* Fan of He et al. (1995, p. 81, pl. 58, figs. 4, 24–26) and *B. xinjiangensis* Wang and Yang (1998, p. 79, pl. 6, figs. 2–7) have more distinct and wrinkled growth lamellae on the dorsal valve when compared with similar features of the present material.

Superfamily ECHINOCONCHOIDEA Stehli, 1954
Family ECHINOCONCHIDAE Stehli, 1954
Subfamily ECHINOCONCHINAE Stehli, 1954
Tribe CALLIPROTONIINI Lazarev, 1985
Genus CALLIPROTONIA Muir-Wood and Cooper, 1960
CALLIPROTONIA sp.
Figure 4.10–4.11

Description.—Shell small for genus, about 5.2 mm wide and 5 mm long; outline of dorsal valve subcircular; hinge line straight, narrower than greatest width at midvalve. Dorsal valve nearly flat in profile; umbonal region having small swollen node beneath middle of hinge; ears small, cardinal extremities acute; lateral and anterior margins rounded. Shell surface ornamented with low concentric bands; bands distinct, becoming broader and stronger anteriorly, about three per 2 mm on anterior part of valve, covered by spine rows; spine bases small and prostrate on concentric bands; crests of bands relatively sharp with anteriorly steep slope, troughs slightly narrower. Dorsal interior with cardinal ridges and muscle field; cardinal ridges thickened along hinge, gradually becoming thinner laterally, supporting cardinal process; cardinal process trilobate, but poorly preserved; adductor muscle field fan-like, posteriorly bounded by low raised ridges diverged from cardinal ridges, extending anteriorly to about a third of valve floor.

Material.—External and internal molds of an incomplete dorsal valve (NMV P309807, 309808).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species closely approximates the morphological features of *Calliprotonia* Muir-Wood and Cooper, 1960, such as flattened concentric bands and the trifurcate cardinal process. The present material however differs from *C. renfrarum* Muir-Wood and Cooper (1960, p. 247, pl. 81, figs. 1–13) by its smaller size, narrower troughs of concentric bands, and absence of lateral ridges extending around the ears to the lateral margins. *Calliprotonia inexpectum* (Cooper, 1957, p. 48, pl. 8C, figs. 13–26) from the Permian of central Oregon (USA) differs from the present species by its larger size, strongly concave dorsal valve, and the presence of more spine rows on the concentric bands of the dorsal valve, as well as the presence of a prominent median septum in the dorsal interior.

Superfamily LINOPRODUCTOIDEA Stehli, 1954
Family LINOPRODUCTIDAE Stehli, 1954
Subfamily LINOPRODUCTINAE Stehli, 1954
Genus LINOPRODUCTUS Chao, 1927
LINOPRODUCTUS sp.
Figure 4.12–4.13

Description.—Shell small for genus, mostly transverse and subquadrate in outline; greatest width slightly posterior to midvalve; profile weakly concavo-convex; hinge slightly narrower than width. Ventral valve evenly curved in profile; beak strongly curved; costellae numerous, coarse, fairly even with few intercalations, crests rounded with narrower troughs; concentric rugae well developed on posterior part of valve, weaker anteriorly, with broad wrinkles on flanks. Dorsal valve nearly flat to slightly concave in profile; ear small and wrinkled, cardinal extremities acute; costellae finer and sharper than those of ventral valve, numbering about eight to nine per 3 mm on anterior part of valve, interrupted by concentric rugae; concentric rugae irregular but anteriorly increasing in height; spines along hinge only, poorly preserved. Dorsal interior with small and circular alveolus; cardinal ridges thin, with antero-laterally divergent ridges bounding posterior part of muscle field; breviseptum originating from alveolus anteriorly to midvalve, forming low thin ridge; muscle field subtriangular, bisected by breviseptum, extending anteriorly to about a third of dorsal disc.

Material.—An internal mold of a dorsal valve (NMV P309809) and an external mold of a dorsal valve (NMV P309810).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—Despite the poor preservation, the present materials show morphological features of *Linoproductus* Chao, 1927, including a subquadrate outline, ornamentation composed of fine costellae and irregular rugae, rugose ears, and the presence of an alveolus and a long breviseptum in the dorsal interior. This species is characterized by its transverse outline with a hinge slightly narrower than the greatest width of the midvalve. Although both *Productus* (*Linoproductus*?) *mammatus* Keyserling figured by Grabau (1931, p. 288, pl. 29, figs. 10–13) from Mongolia and *Linoproductus* sp. A Gobbett (1964, p. 100, pl. 11, fig. 6) from Svalbard in the Arctic have a transverse outline, they differ from the present species in having their greatest width at the hinge. The specimens figured as *L. liaoningensis* Liu by Fan and He (1999, pl. 19, figs. 13–17) from China is transverse in outline and widest in the midvalve, but it is distinguished from the present specimens by its rounded cardinal extremities and a more convex ventral valve. The lack of a dorsal interior of *L. liaoningensis* makes it difficult to compare them. *Linoproductus cora inganensis* Wang and Yang (1998, p. 99, pl. 16, figs. 11–17) from China is also similar to our species, as both have the greatest width on the midvalve, wrinkled ears, and a breviseptum about half the length of the dorsal valve, but the former is much larger in shell size and more elongate in outline.

Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily ORTHOTETOIDEA Waagen, 1884
Family ORTHOTETIDAE Waagen, 1884
Genus ORTHOTETES Fischer de Waldheim, 1829
ORTHOTETES sp.
Figure 4.14

Description.—Large shell fragment slightly convex in profile, concentrically wrinkled, and partly distorted; anterior margin relatively rounded. Shell surface ornamented by numerous costellae; costellae fine, distinct, interrupted by concentric growth lirae, increasing in number anteriorly by bifurcations, about 13 per 10 mm on anterior margin; crests of costae nearly flat and troughs much narrower than crests; concentric growth lamellae present at irregular intervals.

Material.—An internal mold of a shell fragment showing shell ornament (NMV P309811).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—Although the present material does not preserve the hinge part or internal structures, it nevertheless exhibits shell ornamentation characteristic of the genus *Orthotetes* Fischer de Waldheim, 1829. *Orthotetes radiata* Fischer de Waldheim, 1850 from Russia resembles the present specimen in its distorted valve with well-developed concentric lirae on the anterior margin, but the former has relatively continuous costellae. The specimens figured as *O. plana* Ivanov by Sarycheva and Sokolskaya (1952, p. 52, pl. 8), also from Russia, are closely similar to this species in having a large shell, nearly flat convexity, and costellation interrupted by concentric growth lirae. Two comparable Chinese species, *O. huagongensis* Liao (1979, p. 533, pl. 1, figs. 28–30) and *O. regularis* (Waagen) figured by Wang and Yang (1998, p. 65, pl. 2, figs. 10–15), differ from this species by having a more strongly convex valve with continuous costellae.

Family DERBYIIDAE Stehli, 1954
Genus DERBYIA Waagen, 1884
DERBYIA sp.
Figure 5.1–5.6

Description.—Shell of average size for genus; outline transversely subquadrate; profile flatly biconvex, with central valve only shallowly conical, both valves tending to be wrinkled concentrically; interarea high, flat, apsacline; pseudodeltidium short, evenly arched. Shell surface ornamented by

FIGURE 5—*1–6*, *Derbyia* sp.: *1*, NMV P309812, ventral view of latex cast of a ventral external mold, ×2; *2*, NMV P309817, dorsal view of latex cast of a dorsal external mold with partial ventral interior, ×2; *3*, NMV P309813, ventral view of latex cast of an incomplete ventral external mold, ×1; *4*, NMV P309814 (a) and NMV P309815 (b), latex cast of external mold of two incomplete ventral valves, ×1; *5*, NMV P309814, posterior view of latex cast of an incomplete ventral external mold, ×1; *6*, NMV P309816, ventral view of an internal mold of ventral valve, ×1; *7–11*, *Meekella* sp.: *7*, NMV P309819, ventral view of an incomplete ventral internal mold, ×1.5; *8*, NMV P309820, ventral view of an incomplete ventral internal mold, ×1.5; *9*, NMV P309822, shell fragment showing shell ornamentation, ×2; *10*, NMV P309818, latex cast of an incomplete ventral external mold, ×2; *11*, NMV P309821,

numerous costellae; costellae very sharp in cross-section view, increasing in number anteriorly by intercalation; small pits randomly dispersed on shell surface. Ventral interior with strong dental plates; dental plates short and slightly diverged; floor of valve reflecting external costellae, with striae becoming deeper at margin.

Material.—Four ventral external molds (NMV P309812–309815), a ventral internal mold (NMV P309816) and a dorsal external mold (NMV P309817).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—*Derbyia*? sp. Ozaki (1931, p. 148, pl. 13, figs. 10–12) from North China may be identical with the present species in most features. In shell size and surface ornamentation, this species is also quite similar to *D. crassa* (Meek and Hayden) described by Dunbar and Condra (1932, p. 79, pl. 3, figs. 1–12) from Nebraska, except for the presence of small pits on shell surface.

Family MEEKELLIDAE Stehli, 1954
Subfamily MEEKELLINAE Stehli, 1954
Genus MEEKELLA White and St. John, 1867
MEEKELLA sp.
Figure 5.7–5.11

Description.—Shell moderate to large for genus; outline subquadrate; widest at anterior to midlength; hinge narrower than shell width; cadinal extremities acute; lateral margin broadly rounded. Ventral valve nearly flat, except for swollen and short ridge-like umbo; shell surface ornamented with numerous plications and costellae; plications broadly radial, variable in width and inter-plicae trough, commencing from posterior part of shell, within about 10 mm of umbo; costellae fine but distinct, originating from beak, numbering about 10 in 5 mm on midvalve, increasing anteriorly by intercalation, crests of costellae sharp and scabrous, with wider troughs between them; concentric growth lamellae present at irregular intervals, distinct close to margin.

Material.—An incomplete ventral external mold (NMV P309818), three incomplete ventral internal molds (NMV P309819–309821) and a shell fragment (NMV P309822).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—Shell plications vary in width and shape in these specimens. Shi et al. (2001) showed that juveniles of some species of *Meekella*, White and St. John, 1867 do not have plications on the shell surface. Therefore, the variation of plication might be related to the degree of shell growth as a feature of ontogeny. The present species is similar to *M. bisculpta* Grant (1976, p. 58, pl. 10, figs. 1–35) from Southern Thailand in outline but closer to *M. addicta* Grant (1976, p. 57, pl. 9, figs. 1–51), also from South Thailand, in plication patterns, which begin in both species from near the beak. The incomplete preservation of the present specimen, however, prevents a definite assignment to either of the Thais species at the specific level.

Class RHYNCHONELLATA Williams et al., 1996
Order ORTHIDA Schuchert and Cooper, 1932
Suborder DALMANELLIDINA Moore, 1952
Superfamily DALMANELLOIDEA Schuchert, 1913
Family RHIPIDOMELLIDAE Schuchert, 1913
Subfamily RHIPIDOMELLINAE Schuchert, 1913
Genus RHIPIDOMELLA Oehlert, 1890
RHIPIDOMELLA PARVA new species
Figure 6.1–6.10

Diagnosis.—Small and weakly convex *Rhipidomella*; costellae low, separated by interspaces narrower than costellae in width.

Description.—Shell small for genus, about 7 mm wide and 7 mm long in the largest dorsal valve; outline subovate to subtriangular; greatest width slightly anterior to midvalve; hinge narrow, about one-third shell width; profile slightly biconvex. Ventral valve slightly larger than dorsal valve; outline of dorsal valve subcircular; umbonal regions of both valves swollen, the rest nearly flat; beaks very close to each other, ventral beak longer, dorsal beak pointed and rounded; interarea low and narrow. Shell surface ornamented with costellae, originating from umbonal region; costellae shallow, uniform in size, increasing anteriorly by intercalation, 10–12 per 3 mm on midvalve, but weaker near margins; interspaces narrower than costellae; growth lamellae weak, closely spaced near valve margin; surficial pits at some specimens small and slightly elongated, irregularly dispersed on costellae; sulcus and fold weak or absent. Ventral interior with short and low median septum extending anteriorly to midvalve; muscle scars subcircular and shallow on posterior part of valve floor, bisected by median septum; floor of valve marked by striae, reflecting external costellae. Dorsal interior with small and blunt cardinal process in middle of hinge plate; crura short, divergent, supported by undifferentiated hinge plate, but poorly preserved; median septum and muscle scars not observed; striae of dorsal valve floor similar to ventral valve.

Etymology.—From the Latin adjective *parva*, very small.

Type.—Holotype, a complete dorsal external mold with posterior part of ventral valve (NMV P309823, Fig. 6.1–6.2).

Other material.—Four ventral external molds (NMV P309824–309827), an incomplete ventral internal mold (NMV P309828) and a dorsal internal impression (NMV P309829).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species is characterized by its small size, weak convexity, and the presence of a very small cardinal process for the genus. The specimens figured as *Rhipidomella cora* d'Orbigny by Ozawa (1927, p. 84, pl. 7, figs. 27, 30) from northeast China is similar to *R. parva* in size but has a different transverse outline. *Rhipidomella* cf. *cora* d'Orbigny figured by Ozaki (1934, p. 92, pl. 19, fig. 2) from North Korea also resembles this species in the internal structure of valve, but it has a larger and more circular ventral valve.

←

ventral view of an incomplete ventral internal mold, ×1.5; *12–14*, *Cleiothyridina* sp.: *12*, NMV P309848, ventral view of latex cast of a ventral external mold, ×2; *13*, NMV P309849, dorsal view of latex cast of a dorsal external mold, ×2; *14*, NMV P309850, latex cast of a fragmentary ventral external mold, ×2; *15–20*, *Hustedia paula* Roberts, 1971, all ×3: *15*, NMV P309852, ventral view of latex cast of a ventral external mold; *16*, NMV P309851, lateral view of latex cast of external mold of a conjoined valve; *17*, NMV P309854, dorsal view of latex cast of a dorsal external mold; *18*, NMV P309855, dorsal view of latex cast of a dorsal external mold; *19*, NMV P309853, ventral view of latex cast of a ventral external mold; *20*, NMV P309856, dorsal view of latex cast of external mold of a dorsal valve with foramen of ventral valve; *21–22*, *Martinia* sp.: *21*, NMV P309857, ventral view of latex cast of a ventral external mold, ×2; *22*, NMV P309858, ventral view of a ventral internal mold, ×3. Scale bars are 5 mm.

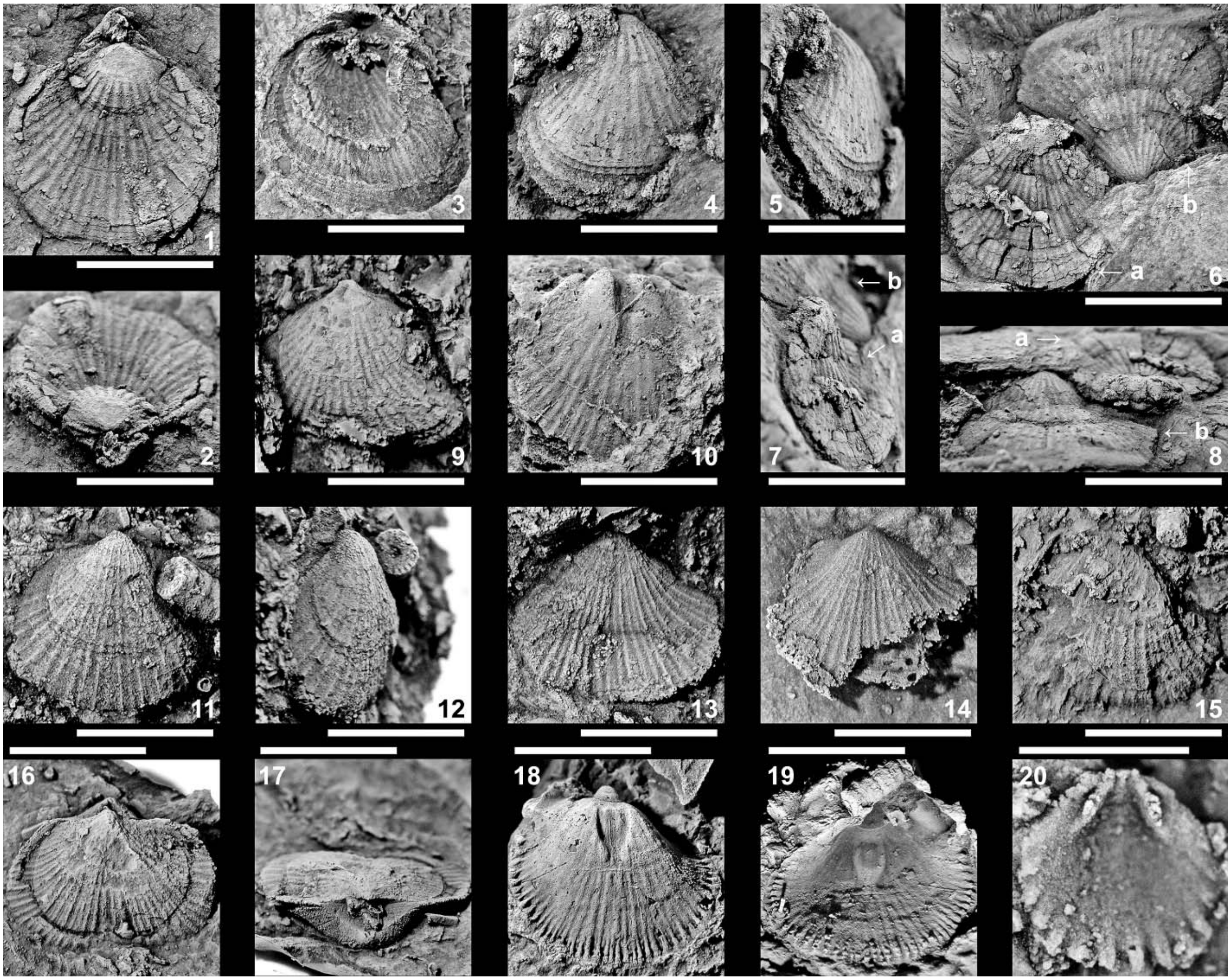


FIGURE 6—*1–10*, *Rhipidomella parva* n. sp., all ×4: *1–2*, NMV P309823, holotype, dorsal and posterior views of latex cast of a complete dorsal external mold with posterior part of ventral valve; *3*, NMV P309829, an internal impression of dorsal valve; *4–5*, NMV P309824, ventral and lateral views of latex cast of a ventral external mold; *6–8*, NMV P309825 (a) and NMV P309826 (b), ventral, lateral, and posterior views of latex cast of two ventral external molds; *9*, NMV P309827, ventral view of latex cast of an incomplete ventral external mold; *10*, NMV P309828, ventral view of a ventral internal mold; *11–15*, *Rhipidomella* sp. A, all ×4: *11–12*, NMV P309830, ventral and lateral views of latex cast of a ventral external mold; *13*, NMV P309831, ventral view of latex cast of a ventral external mold; *14*, NMV P309832, ventral view of latex cast of an incomplete ventral external mold; *15*, NMV P309833, ventral view of latex cast of an incomplete ventral external mold; *16–20*, *Rhipidomella* sp. B.: *16–17*, NMV P309834, dorsal and posterior views of latex cast of a dorsal external mold with ventral fragment, ×4; *18–19*, NMV P309835, a ventral internal mold and the latex cast, ×4; *20*, NMV P309836, latex cast of a juvenile ventral internal mold, ×25. Scale bars are 5 mm except *20*, where bar is 1 mm.

Rhipidomella longwangtangensis Fan (*in* He et al., 1995, p. 77, pl. 54, figs. 45–48) from China resembles this species in size but is more convex in transverse view. *Rhipidomella pecosi* (Marcou) figured by Wang and Yang (1998, p. 62, pl. 2, fig. 5) from China is similar in size and outline, but it has well-developed growth lamellae. *Rhipidomella* sp. Tazawa (1984, p. 305, pl. 61, figs. 5–7) from Japan from the Visean is large in size and has large and distinct muscle scars in the interior of the ventral valve. *Rhipidomella cordialis* Grant (1976, p. 37, pl. 2, figs. 31–41; pl. 3, figs. 1–53), the Permian species from Thailand, is similar to this species in outline and the existence of surficial pits on the valve, but it differs in having stronger convexity, more distinct growth lines, weaker costellae, and larger cardinal process. The present species has some features characteristic of *Perditocardinia* Schuchert and Cooper, 1931, but the latter genus does not have interareas, which are very distinctive in *Rhipidomella*.

RHIPIDOMELLA sp. A
Figure 6.11–6.15

Material.—Four ventral external molds (NMV P309830–309833).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species is similar to *Rhipidomella parva* in size and convexity but differs in having costellae that are narrower than the interspaces, and it lacks surficial pits. Also, this species is slightly wider and more pentagonal in outline and lacks growth lamellae on the marginal part of valve.

RHIPIDOMELLA sp. B
Figure 6.16–6.20

Material.—A dorsal external mold conjoined with posterior part of ventral valve (NMV P309834) and two ventral internal molds (NMV P309835, 309836).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species is also comparable to *Rhipidomella parva* in size and *Rhipidomella* sp. A in outline but is distinct in having costae that are as wide as their interspaces and become stronger near the margins. This species is also characterized by its strongly convex ventral valve and umbonal region. The ventral interior of this species has strong, knob-like hinge teeth and a thickened muscle area. The ventral interior resembles that of small specimens of *R. cordialis* Grant (1976, p. 37, pl. 2, fig. 31–33) from Thailand. *Perditocardinia* aff. *P. dubia* (Hall) figured by Schuchert and Cooper (1932, pl. 19, figs. 14, 15) from the Mississippian strata of Missouri (USA) is also similar to the present specimens in shell ornamentation and muscle scars of the ventral interior but the former lacks interareas.

Order RHYNCHONELLIDA Kuhn, 1949
Superfamily STENOSCISMATOIDEA Oehlert, 1887
Family STENOSCISMATIDAE Oehlert, 1887
Subfamily STENOSCISMATINAE Oehlert, 1887
Genus STENOSCISMA Conrad, 1839
STENOSCISMA WOOI new species
Figure 7.1–7.20

Stenoscisma mutabilis (CHERNYSHEV); LI AND GU, 1980, p. 486, pl. 1, fig. 4.

Diagnosis.—*Stenoscisma* with relatively small camarophorium; both sulcus and costae originating anterior to umbo; costation distinct on sulcus and fold but weaker laterally on flanks.

Description.—Shell small for genus, ranging from 4 to 20 mm in visible width, widest at midvalve; outline slightly rectangular to subpentagonal; moderately unequally biconvex in profile. Ventral valve moderately curved in lateral view; umbonal region most convex, gradually flattened anteriorly; cardinal extremities bluntly rounded; sulcus narrow, generally weak to moderately developed, originating anterior to umbo; costae strong and well-developed in sulcus, increasing anteriorly by intercalation, numbering about five in 5 mm, starting from anterior part of umbo, separated by equidimensional or slightly narrower interspaces, but weaker to absent laterally on flanks; growth lamellae weak, only present on marginal part of valve. Dorsal valve more convex than ventral valve, greatest at umbo; flattened anteriorly; fold weak; pattern of costae similar to that of ventral valve. Ventral interior with well-developed and deep spondylium; median septum low near apex, higher anteriorly, highest at anterior edge of spondylium, then lowering toward anterior margin, extending forward to beyond mid-length; distinct muscle markings not observed within spondylium; pallial markings present in some specimens. Dorsal interior with small and low cardinal process; cardinal process trilobed on raised posterior surface of hinge plate, with shallow and weak diductor marks on its lateral sides; hinge plate undivided, broad in middle, narrower laterally; camarophorium oval in shape, shallow, and small, about 1.5 mm wide, 2 mm long, ventrally curved on high median septum; median septum thinner and lower toward anterior margin; intercamarophorial plate thin and low, but distinct; adductor scars absent.

Etymology.—Named after J. Woo (Seoul National University) who found some of the specimens for the first time.

Type.—Holotype, an internal mold of conjoined valve (NMV P309837, Fig. 7.1–3).

Other material.—Four internal molds of conjoined valves (NMV P309838–309841), a ventral valve (NMV P309842), a ventral external mold (NMV P309843), a dorsal external mold (NMV P309844), two ventral internal molds (NMV P309845–309846) and a dorsal internal mold (NMV P309847).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek); Pennsylvanian, northeastern China.

Discussion.—Ozaki (1931) described three new species from northeast China: *Rhynchonella*? *gregaria* var. *biplicata*, *Camarophoria tanankouensis*, *C. shanhsiensis*. Later, all of these were assigned to *Stenoscisma* Conrad, 1839 in view of their outline and costation by Wang et al. (1964). *Stenoscisma wooi* is different from these three species in having costae originating from the anterior part of the umbo and in having a weaker sulcus and fold. *Stenoscisma mutabilis* (Chernyshev, 1902, p. 491, pl. 22, fig. 18; pl. 23, fig. 10; pl. 45, figs. 1–15, pl. 46, fig. 14) from the Carboniferous strata of Russia is similar to *S. wooi* in the costation pattern on the flanks but differs in having a broader sulcus and costae originating from umbo. *Stenoscisma wooi* is also distinguished from *S. venustum* (Girty, 1909, p. 303, pl. 31, figs. 6–6c) in Texas by the presence of a very small camarophorium, despite their similarity in outline and costation. *Stenoscisma* sp. A figured by Grant (1976, p. 186, pl. 50, figs. 1–8) from the Permian of Thailand also has a small camarophorium, but its costae are almost restricted to the fold, with nearly smooth flanks.

Li and Gu (1980, p. 486) reported two specimens of *Stenoscisma mutabilis* (Chernyshev) from northeast China. However, one of them (pl. 1, fig. 4) differs from *S. mutabilis* in having a narrow sulcus and costae commencing anterior to the umbo. These characters of the specimen are completely comparable to those of *S. wooi*; therefore, the specimen should be assigned to *S. wooi*. On the other hand, the second specimen figured by Li and Gu (1980, pl. 1, fig. 5) is similar to *S. mutablis* in having a relatively broader sulcus and costae starting from the umbo.

Juvenile specimens of *Stenoscisma wooi* show morphological characters including an elongated outline and a sulcus bearing weaker costae starting from the more anterior part of valve. These features are similar to the morphology of *S. yanjiensis* Li and Gu (1980, p. 486, pl. 1, fig. 11) from China. However, a precise comparison between them is not possible; detailed examination of *S. yanjiensis* is limited due to the poor preservation.

Order ATHYRIDIDA Boucot, Johnson, and Staton, 1964
Suborder ATHYRIDIDINA Boucot, Johnson, and Staton, 1964
Superfamily ATHYRIDOIDEA Davidson, 1881
Family ATHYRIDIDAE Davidson, 1881
Subfamily CLEIOTHYRIDININAE Alvarez, Rong, and Boucot, 1998
Genus CLEIOTHYRIDINA Buckman, 1906
CLEIOTHYRIDINA sp.
Figure 5.12–5.14

Description.—Shell small for genus, about 10 mm wide and 12 mm long in nearly complete ventral valve; outline slightly elongated, slightly longer in ventral valve, with maximum width at midvalve; profile gently biconvex, most convex on umbonal region, almost flat near midlength in both valves; anterolateral margin of valve rounded; sulcus and fold not prominent. Shell surface ornamented with concentric lamellae; lamellae originating from beak, irregular in intervals but generally narrow, numbering 15 per 4 mm on anterior part of valve, somewhat narrower toward margin, dispersed on whole valve but more distinct on anterior part of valve, all concentric lamellae bearing spine bases; spines minute, prone, fringe, broader and longer toward margin of valve.

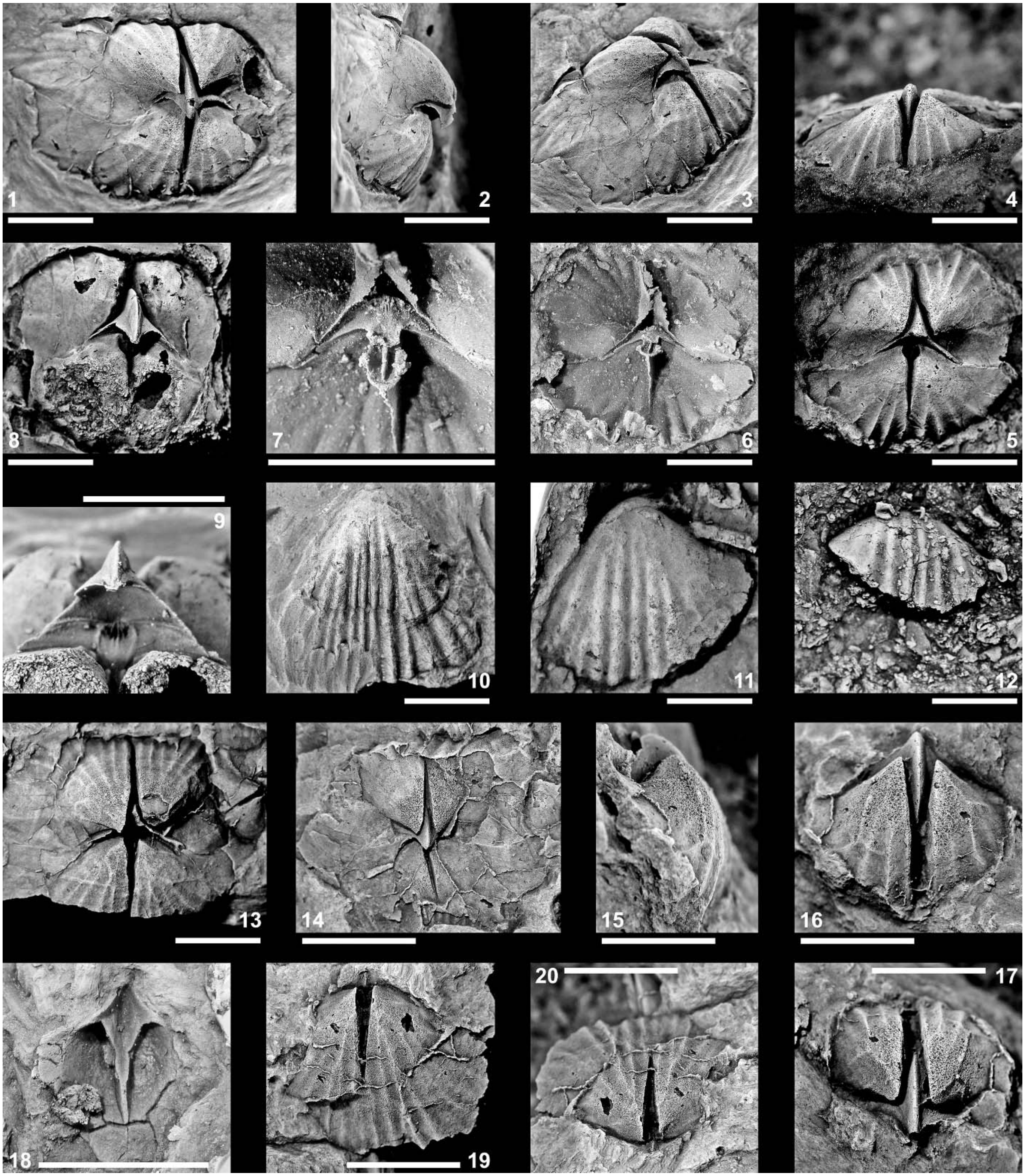


FIGURE 7—*1–20*, *Stenoscisma wooi* n. sp.: *1–3*, holotype, NMV P309837, posterior, lateral, and oblique views of internal mold of a conjoined shell, ×3; *4–7*, NMV P309838, ventral and posterior views of internal mold of a conjoined shell, anterior view of the latex cast, and magnified spondylium and camarophorium, ×3, ×3, ×3, ×8; *8–9*, NMV P309839, posterior and dorsal views of internal mold of a conjoined shell, ×3, ×5; *10*, NMV P309842, ventral view of a ventral valve, ×3; *11*, NMV P309843, ventral view of latex cast of a ventral external mold, ×3; *12*, NMV P309844, dorsal view of latex cast of a dorsal external mold, ×3; *13*, NMV P309840, posterior view of internal mold of a conjoined shell, ×3; *14*, NMV P309841, posterior view of internal mold of a conjoined shell, ×4; *15–17*, NMV P309845, lateral, ventral, and posterior views of a ventral internal mold, ×4; *18*, NMV P309846, latex cast of a juvenile ventral internal mold, ×6; *19–20*, NMV P309847, dorsal and posterior views of a dorsal internal mold, ×4. Scale bars are 5 mm.

Material.—A nearly complete ventral external mold (NMV P309848), a complete dorsal external mold (NMV P309849) and a fragmentary ventral external mold (NMV P309850).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—The present specimens are closely comparable to small specimens of *Cleiothyridina seriata* Grant (1976, p. 199, pl. 53, figs. 1–30; pl. 54, figs. 1–62; text-fig. 18) from the Permian of Thailand in elongated outline, weak convexity, and presence of fringe-like spines, but differs in having spine bases on all lamellae. *Cleiothyridina pectinifera* (Sowerby) figured by Grabau (1934, p. 111, pl. 7, fig. 11) from South China is also similar to the present specimens in small size and weak convexity. However, this species differs from the holotype of *C. pectinifera* (Sowerby, 1840 *in* 1840–1846, p. 14) in having a small, flat shell and longitudinal outline. Another comparable species from China, *C. royssii* (L'Eveille) of Grabau (1934, p. 110, pl. 7, figs. 9, 10) and of Ozaki (1939, p. 270, pl. 43, figs. 8a–8q) are generally wider in outline and more convex than the present specimens.

Suborder RETZIIDINA Boucot, Johnson, and Staton, 1964
Superfamily RETZIOIDEA Waagen, 1883
Family NEORETZIIDAE Dagys, 1972a
Subfamily HUSTEDIINAE Grunt, 1986
Genus HUSTEDIA Hall and Clarke, 1893
HUSTEDIA PAULA Roberts, 1971
Figure 5.15–5.20

Hustedia paula ROBERTS, 1971, p. 176, pl. 37, figs. 12–26.

Hustedia aff. *paula* Roberts; NAZER, 1977, p. 3, pl. 2, figs. 5–11.

Hemiplethorhynchus sp. YANG, LEE, AND CHEONG, 1984, p. 153, pl. 4, fig. 3.

Desquamatia sp. cf. *D. quadrata* WANG ET AL.; YANG, LEE, AND CHEONG, 1984, p. 153, pl. 4, figs. 1, 2, 4–9.

Description.—Shell average size for genus, ranging from 2.2 to 5.0 mm in width and 2.5 to 9.0 mm in length on ventral valve; outline elongate to suboval, widest at midvalve; hinge narrow, about half of shell width; profile moderately biconvex. Ventral valve longer than dorsal, constantly convex; umbo not swollen; foramen small and circular with diameter of about 0.5 mm; interarea low and narrow; sulcus shallow and narrow. Dorsal valve suboval in outline, equally convex to slightly more convex than ventral valve; dorsal beak small and blunt; fold weak. Shell surface ornamented with nearly uniform costae in width; costae normally distinct, narrow and curved antero-laterally, originating from beak, numbering 12 to 19 on ventral valve but typically 17, sometimes increasing by intercalation, two median costae on both valves, crests rounded; interspaces flat-bottomed and usually wider than costae; growth lamellae unusually developed on marginal part of valve in some specimens. Shell interiors unknown.

Material.—An incomplete external mold of a conjoined valve (NMV P309851), two ventral external molds (NMV P309852, 309853), and three dorsal external molds (NMV P309854-309856).

Occurrence.—Mississippian (Visean), Australia; Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—The present specimens are identical to the specimens *Hemiplethorhynchus* sp. and *Desquamatia* sp. cf. *D. quadrata* Wang et al. reported by Yang et al. (1984) from a locality of the present study. However, they cannot be assigned to *Hemiplethorhynchus* von Peetz, 1898 or *Desquamatica* Alekseeva, 1960 due to their elongated outline, relatively strong costae, and straight commissure. These characteristics indicate that the species is better associated with *Hustedia paula* Roberts, 1971 from the Visean beds of Australia. This species also resembles *H. deminuta* Wang (1955, p. 164, pl. 97, figs. 23–26) from the Carboniferous of China in its relatively elongated outline and number of costae but has much narrower costae and wider interspaces. The specimen figured as *Hustedia tulensis* (Pander) by Sarytcheva and Sokolskaya (1952, p. 231, pl. 68, fig. 393) from the Moscow Basin of Russia is similar in the number of costae, but it has a wider outline.

Order SPIRIFERIDA Waagen, 1883
Suborder SPIRIFERIDINA Waagen, 1883
Superfamily MARTINIOIDEA Waagen, 1883
Family MARTINIIDAE Waagen, 1883
Subfamily MARTINIINAE Waagen, 1883
Genus MARTINIA M'Coy, 1844
MARTINIA sp.
Figure 5.21–5.22

Description.—Shell small for genus, about 16 mm wide and 12 mm long in the largest ventral valve; outline subtriangular to subpentagonal and slightly transverse; greatest width at midvalve. Ventral valve moderately convex in lateral profile, most convex at umbo and flattened anteriorly, but evenly and moderately convex in anterior view; beak acute and strongly curved; umbonal slope steep; sulcus weak, originating from midvalve; shell surface smooth, micro-ornament not observed. Ventral interior with median groove and lateral pallial markings; median groove thin, shallow, extending anterior to midvalve; pallial markings weak, like thin and low ridges, observed only on posterior part of valve floor, somewhat symmetrical with respect to median groove; muscle marks absent.

Material.—A ventral external mold (NMV P309857) and a ventral internal mold (NMV P309858).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species resembles *Martinia mongolica* Grabau (1931, p. 180, pl. 15, figs. 1–4; pl. 18, fig. 1) from Mongolia in its small shell size and similar outline, but *M. mongolica* has well-recognized costellae and concentric growth lines on the shell surface. *Martinia* sp. He et al. (2005, p. 935, figs. 4.15–4.17), from the Permian of China, shows an internal morphology of a ventral valve composed of a median groove and radial pallial markings, which is similar to that of the present specimens. But the former differs from the latter by having a large-sized shell. The present specimens are closely similar to *M. semiplana* Waagen of Ozawa (1927, p. 87, pl. 7, figs. 18–19) and *M.* cfr. *semiplana* Waagen of Ozaki (1931, p. 81, pl. 9, figs. 11–13) from northeast China in having a small-sized shell with a subpentagonal outline, a weak sulcus, and smooth shell ornamentation on the ventral valve. However, it is difficult to assign it at the species level due to the lack of a dorsal valve in the present species.

Superfamily SPIRIFEROIDEA King, 1846
Family CHORISTITIDAE Waterhouse, 1968
Subfamily CHORISTITINAE Waterhouse, 1968
Genus CHORISTITES Fischer de Waldheim, 1825
CHORISTITES PAICHINGIENSIS Ozaki, 1931
Figure 8.1–8.9

Spirifer (*Choristites*) *paichingiensis* OZAKI, 1931, p. 47, pl. 3, figs. 9–10.

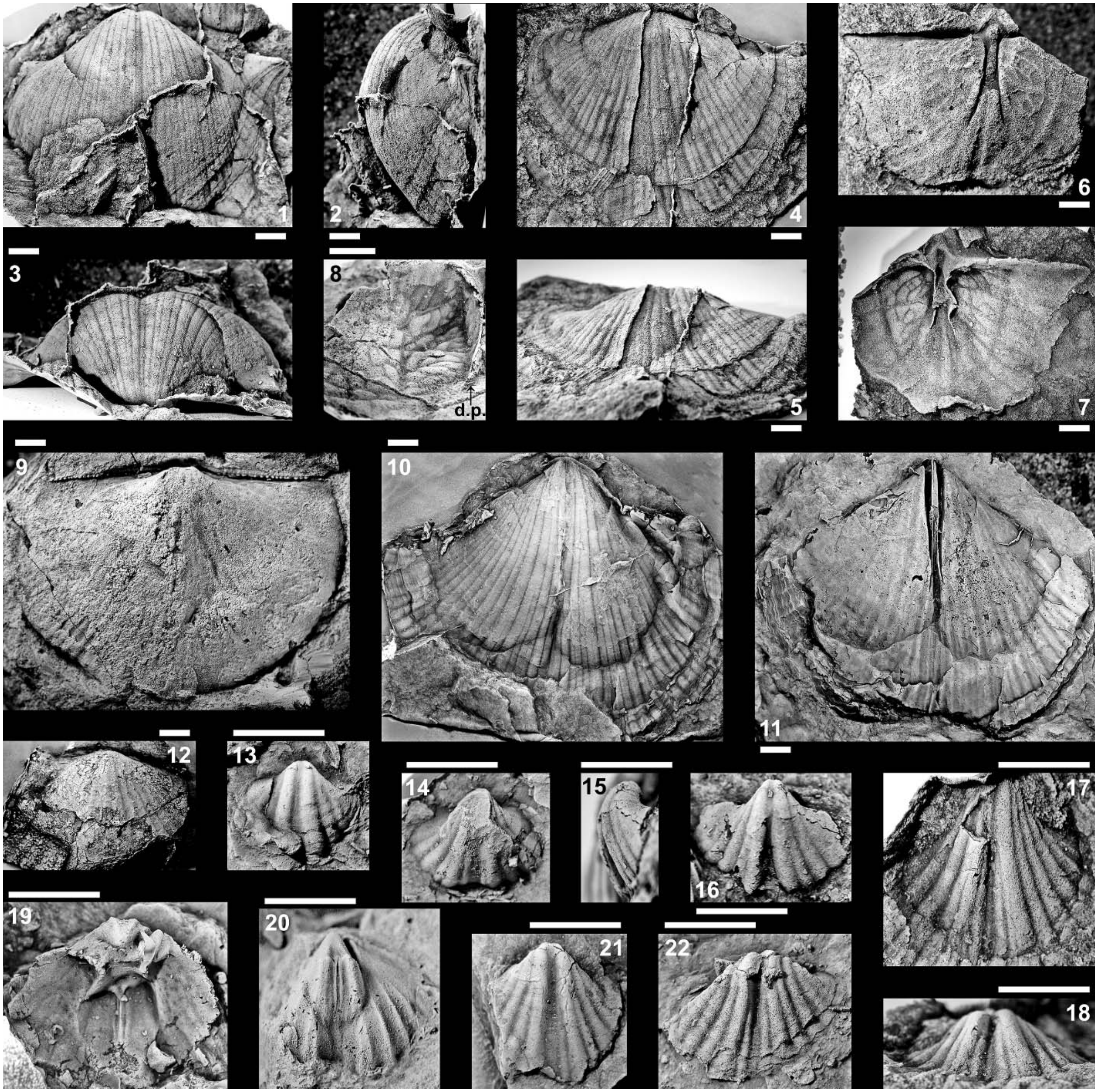


FIGURE 8—*1–9*, *Choristites paichingiensis* Ozaki, 1931: *1–3*, NMV P309859, ventral, lateral, and posterior views of latex cast of a ventral external mold, ×1; *4–5*, NMV P309860, dorsal and anterior views of latex cast of a dorsal external mold, ×1; *6–7*, NMV P309861, an internal mold of ventral valve and the latex cast, ×1; *8*, NMV P309862, anterior view of latex cast showing ventral vascular system, d.p.: dental plate, ×1.5; *9*, NMV P309863, dorsal view of a dorsal internal mold, ×1; *10–12*, *Choristites* sp.; *10*, NMV P309864, ventral view of latex cast of a ventral external mold, ×1; *11*, NMV P309865, ventral view of a ventral internal mold, ×1; *12*, NMV P309866, dorsal view of latex cast of a dorsal external mold, ×1; *13–22*, *Spiriferella*? sp., all ×3; *13*, NMV P309867, ventral view of latex cast of a ventral external mold; *14*, NMV P309868, ventral view of latex cast of a ventral external mold; *15–16*, NMV P309869, lateral and ventral views of a ventral external mold; *17–18*, NMV P309870, ventral and anterior views of latex cast of a ventral external mold; *19*, NMV P309873, latex cast of a ventral internal mold; *20*, NMV P309874, ventral view of a ventral internal mold; *21*, NMV P309871, ventral view of latex cast of a ventral external mold; *22*, NMV P309872, ventral view of latex cast of a ventral external mold. Scale bars are 5 mm.

Choristites paichingiensis OZAKI; WANG, CHING, AND FANG, 1964, p. 492, pl. 90, figs. 5–7; FAN AND HE, 1999, pl. 27, fig. 1.

Diagnosis.—*Choristites* with widest hinge line, very narrow sulcus, slightly divergent dental plate, numerous small denticles along hinge line, and well-developed reticulated vascular system.

Description.—Shell of average size for genus, about 45 mm wide and 43 mm long in largest ventral valve; greatest width at hinge; outline subcircular; biconvex in profile. Ventral valve strongly convex in profile; umbonal region slightly swollen;

sulcus originating from beak, very narrow but distinct anteriorly; costae numerous, shallow, originating from beak and anteriorly increasing by bifurcation; interspaces much narrower than costae; concentric growth lamellae well developed on marginal part of valve. Dorsal valve less convex than ventral valve in profile; numerous small denticle grooves well-developed along hinge line; fold very weak, originating from beak; costae similar to that of ventral valve. Ventral interior with slightly divergent dental plates; dental plates long, extending anteriorly nearly to midvalve; vascular system well-impresssed and reticulate.

Material.—A ventral external mold (NMV P309859), a dorsal external mold (NMV P309860), two ventral internal molds (NMV P309861, 309862) and a dorsal internal mold (NMV P309863).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek), Pennsylvanian, northeastern China.

Discussion.—The present specimens are very similar to *Choristites paichingiensis* Ozaki, 1931 in outline and in the wide hinge line and narrow sulcus as well as in the pattern of costation. *Choristites paichingiensis* was recognized based on two incomplete specimens from northeastern China and lacks a detailed diagnosis. Since 1931, *C. paichingiensis* has seldom been reported from anywhere in East Asia. *Choristites paichingiensis* from Taebaek contains previously unknown internal structures, including the existence of numerous small denticles along the hinge line and a well-developed and complex vascular system. In addition, as Ozaki (1931) mentioned, young specimens of *C. paichingiensis* display a wider outline.

Choristites paichingiensis is similar to *C. weiningensis* (Grabau) figured by Chao (1929, p. 23, pl. 4, figs. 7, 8) and *C. yuani* Chao (1929, p. 28, pl. 3, fig. 8) from the Carboniferous of China in having flat costae. However, *C. weiningensis* has a much more distinct fold, and *C. yuani* is characterized by a well-developed sulcus on the anterior of the dorsal valve as well as a wide outline.

CHORISTITES sp.
Figure 8.10–8.12

Description.—Shell of moderate size for genus, about 56 mm wide and 47 mm long in nearly complete specimen; greatest width at midvalve; outline transversely subpentagonal, with rounded anterior and lateral sides; biconvex in profile. Ventral valve gently convex in profile; umbonal region moderately convex, gradually flattened anteriorly and laterally; interarea present, but poorly preserved; sulcus originating from umbo, narrow and weak on umbonal region, broaden anteriorly from midvalve; costae numerous, shallow but distinct, originating from umbonal region and anteriorly increasing by bifurcation, broad near sulcus, about three in 5 mm on midvalve, but laterally narrower, about four in 5 mm; interspaces much narrower than costae; concentric growth lamellae observed only on marginal part of valve. Dorsal valve most convex at umbo; fold shallow but distinct, beginning from umbo; costae similar to that of ventral valve. Ventral interior with nearly parallel dental plates; dental plates long, extending anteriorly nearly to midvalve, then combined into low median ridge on floor of midvalve; spaces between dental plates variable but generally narrow; median ridge short and low; muscle scars not observed; floor of valve reflecting external costae, with numerous striae becoming more distinct at anterior part.

Material.—A ventral external mold (NMV P309864), a ventral internal mold (NMV P309865) and a dorsal external mold (NMV P309866).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species is more similar to *Choristites paichingiensis* in many features than it is to any other *Choristites* species. However, it can be distinguished by its completely parallel and long dental plates, as well as by its wider outline, a broad sulcus, and a well-developed fold.

Family SPIRIFERELLIDAE Waterhouse, 1968
Genus SPIRIFERELLA Chernyshev, 1902
SPIRIFERELLA? sp.
Figure 8.13–8.22

Description.—Shell small for genus, about 11mm wide and 10 mm long in the largest specimen; outline varying from slightly transverse to elongate. Ventral valve gently curved, most convex at umbo, gradually flattened anteriorly and laterally; beak short, acute, gently curved; interarea narrow and low; sulcus narrow and distinct, originating from beak, bounded by two strongest plications, having costae with growth; lateral plications shallow but distinct, beginning within about 2 mm of beak, laterally weaker and narrower, four to six plicae on each flank, increasing anteriorly with growth, crests of plicae rounded with narrow troughs between them; concentric rugae observed in anterior part of valve. Ventral interior with short and strong dental plates; adminicula distinct, divergent, forming outline of muscle area; median septum low, separating muscle area; muscle area large and oval; adductor scars long, narrow, surrounded by large diductor scars.

Material.—Six ventral external molds (NMV P309867-309872) and two ventral internal molds (NMV P309873, 309874).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—Strong plications, divergent dental adminicula, and a deeply impressed muscle area of this species all suggest those of *Spiriferella* Chernyshev, 1902, in spite of its relatively low interarea and absence of micro-ornamentaion. The species figured as *Spirifer* (*Dienerina*) *tibetanus* Diener by Ozaki (1931, p. 70, pl. 8, figs. 3–5) from North China closely resembles the present species in outline, size, and pattern of plications, but it has fewer plications. *Spiriferella wimanni* Grabau (1931, p. 138, pl. 19, figs. 2, 3, 5b; pl. 20, fig. 8; pl. 22, fig. 9; pl. 23, fig. 3) from the Permian of Mongolia is similar to the present species in convexity and plications but has a higher interarea as well as a larger size. *Spiriferella pseudodraschei* Einor (*in* Likharev and Einor, 1939, p. 219, pl. 24, figs. 6–9) from the Permian of Russia also presents similar features to our species in the pattern of plications and in its oval muscle field divided by a low median septum. However, *S. pseudodraschei* has a much higher interarea.

Superfamily PAECKELMANELLOIDEA Ivanova, 1972
Family STROPHOPLEURIDAE Carter, 1974
Subfamily PTEROSPIRIFERINAE Waterhouse, 1975
Genus ALISPIRIFER Campbell, 1961
ALISPIRIFER sp.
Figure 9.1–9.8

Description.—Shell small for genus, ventral valve about 15 mm wide and 5.5 mm long; greatest width at hinge line; hinge straight; outline transverse with acute cardinal extremeties; biconvex in profile. Ventral valve moderately curved in lateral view; umbonal region most convex with steep apical angle; flanks slightly convex with steeper margin; beak small

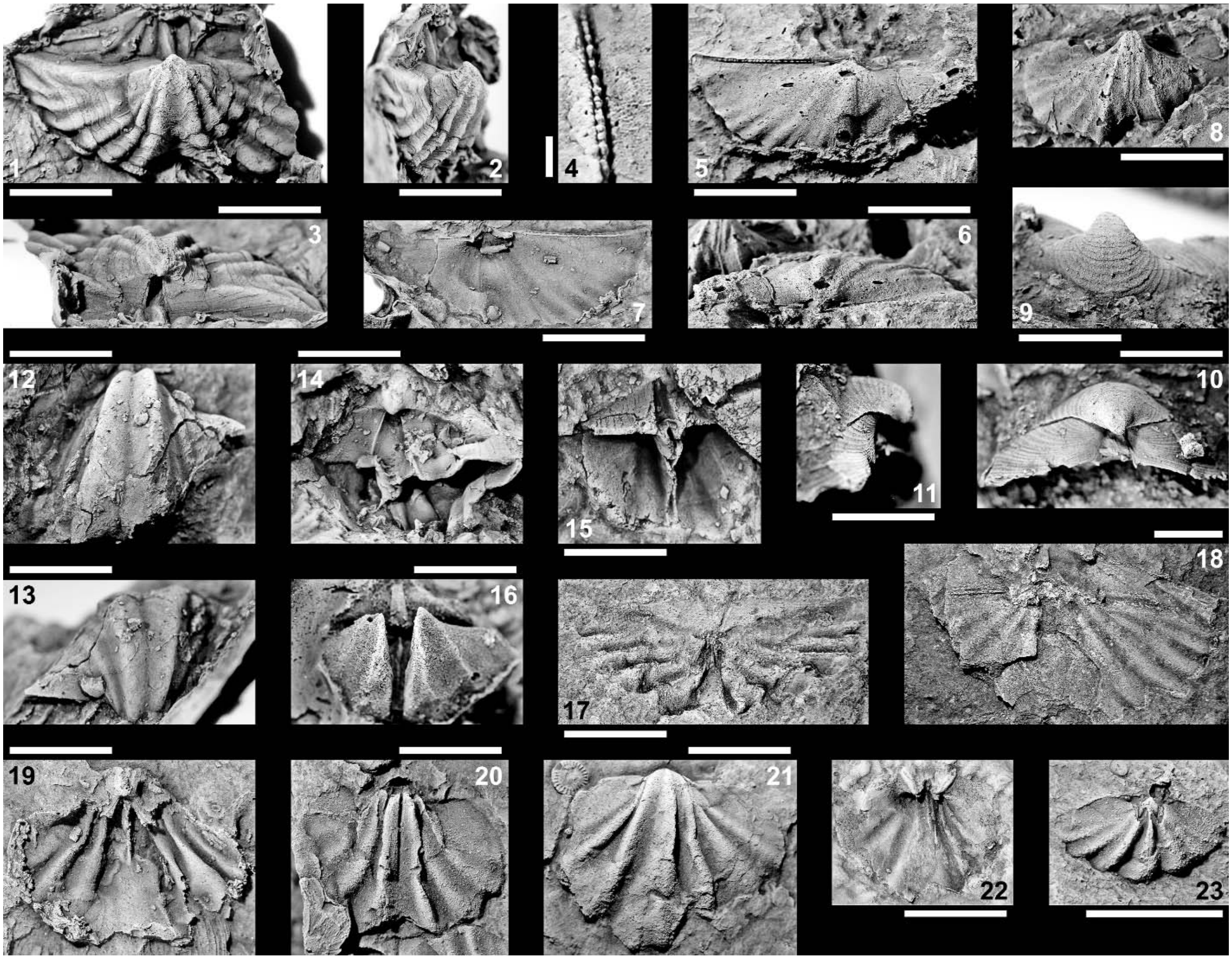


FIGURE 9—*1–8*, *Alispirifer* sp.: *1–3*, NMV P309875, ventral, lateral, and posterior views of latex cast of a ventral external mold, ×3; 4–7, NMV P309877, magnified (×6) denticle grooves along hinge line, dorsal and posterior views of a dorsal internal mold, and the latex cast, ×3; 8, NMV P309876, ventral view of latex cast of a ventral internal mold, ×3; *9–11*, *Phricodothyris reticulariformis* (Ozaki, 1931), NMV P309878, posterior, dorsal, and lateral views of latex cast of an incomplete ventral external mold, ×3; *12–16*, *Davidsonina*? sp., all ×3; *12–13*, NMV P309879, ventral and posterior views of latex cast of a ventral external mold; *14*, NMV P309880, latex cast of a ventral internal mold showing high interarea; *15*, NMV P309881, latex cast of a ventral internal mold; *16*, NMV P309882, ventral view of a ventral internal mold; *17–18*, *Punctospirifer*? sp.: *17*, NMV P309883, ventral view of a ventral external mold, ×3; *18*, NMV P309884, ventral view of a ventral external mold, ×2; *19–23*, *Spiriferellina* sp.: *19*, NMV P309885, latex cast of a ventral internal mold, ×3; *20*, NMV P309886, ventral view of a ventral internal mold, ×3; *21*, NMV P309888, dorsal view of latex cast of a dorsal external mold, ×3; *22*, NMV P309887, latex cast of a ventral internal mold, ×3; *23*, NMV P309889, dorsal view of a dorsal internal mold, ×4. Scale bars are 5 mm except 4, where bar is 1 mm.

and acute; interarea triangular and wide, about 2 mm in height, catacline to weakly apsacline, transversely striated by closely-spaced growth lamellae; delthyrium open, narrow, and triangular; sulcus simple, narrow and moderately developed, becoming wider and deeper anteriorly, about 3 mm in width on anterior margin, originating from umbo, bounded by two lateral plications; flanks ornamented by plications; seven plicae on each side of the sulcus; plicae strong and rounded, wider than interspace, emerging from umbonal region, increasing by intercalation on most lateral margins, curved anterolaterally; concentric growth lamellae well-developed on whole surface, irregularly spaced; no capillae. Dorsal valve much less convex than ventral valve; numerous small denticle grooves well developed along hinge line, about 22 per 5 mm; fold low and narrow, without median furrow; ornamentation similar to that of the ventral valve. Ventral interior with thin and low median ridge enclosed parallel, long and shallow grooves; dental plates poorly preserved. Dorsal interior with small and striated cardinal process; crural plates small and divergent, neither reaching valve floor nor supported on adminicula.

Material.—A ventral external mold (NMV P309875), a ventral internal mold (NMV P309876), and a dorsal internal mold (NMV P309877).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—*Alispirifer* Campbell, 1961 is characterized by its outline shape, pattern of plication and growth lamellae, well-developed denticle grooves, and the internal structure of its shell, including a thin median ridge in the ventral valve, and striated cardinal. The present specimens are comparable to the type species, *A. laminosus* Campbell (1961, p. 434, pl. 55, figs.

17–23), but they differ in having a smaller size, a different outline, and wavy plicae. *Alispirifer laminosus undatus* Campbell (1961, p. 437, pl. 63, figs. 3–4) also has wavy plicae but differs from the present species in its more irregular plicae, more than ten on each side of the sulcus, and a longitudinally striated interarea. It also differs from *A. contractus* Maxwell (1964, p. 28, pl. 5, figs. 13–24), *A. laminosus* var. *transversus* var. Maxwell (1964, p. 28, pl. 5, figs. 33–38), and *A. yagonensis* Thompson (*in* Roberts et al., 1976, p. 216, fig. 10) from Australia by its smaller size. *Tylothyris pyramidata* (Chernyshev, 1902, p. 521, pl. 14, figs. 4, 5) from the Pennsylvanian of Russia resembles the present species in small size and transverse outline, but it has a strong fold and straight costae.

Because *Alispirifer* has so far only been reported from the Visean to Bashikirian strata of Gondwana, it has been thought to be an endemic genus. However, the discovery of *Alispirifer* from Sino-Korean strata confirms that the genus had spread into the Paleo-Tethys of low latitudes in Pennsylvanian times. Carter et al. (1994) revised the spiriferid brachiopods and put *Alispirifer* within the family Strophopleuridae because it lacks a ventral median septum. However, one of the present specimens shows the trace of a ventral median septum (Fig. 9.8), a feature that has not been known from other species of *Alispirifer*. Therefore, it is possible that a ventral median septum evolved in some younger species of this genus.

Suborder DELTHYRIDINA Ivanova, 1972
Superfamily RETICULARIOIDEA Waagen, 1883
Family ELYTHIDAE Frederiks, 1924
Subfamily PHRICODOTHYRIDINAE Caster, 1939
Genus PHRICODOTHYRIS George, 1932
PHRICODOTHYRIS RETICULARIFORMIS (Ozaki, 1931)
Figure 9.9–9.11

Squamularia reticulariformis OZAKI, 1931, p. 77, pl. 9, fig. 5.

Phricodothyris reticulariformis (OZAKI); WANG, CHING, AND FANG, 1964, p. 549, pl. 105, figs. 1–4; FAN AND HE, 1999, p. 148, pl. 33, figs. 40–47.

Description.—Ventral valve with short, pointed, incurved beak and moderately convex umbo; hinge line about 16 mm in width; interarea transverse and occupied medially by triangular delthyrium. Concentric lamellae narrow, relatively rounded, and regularly spaced on umbonal region, about 10 lamellae in 5 mm; lamellae and interspaces between lamellae bearing impressions of numerous, short, and thin spines.

Material.—An incomplete ventral external mold (NMV P309878).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek). Pennsylvanian; North China.

Discussion.—In spite of the limited preservation of the specimen showing only the posterior part of the ventral valve, it agrees well with *Phricodothyris reticulariformis* (Ozaki, 1931) from northeast China in shell size and ornamentation. *Squamularia elegantuloides* Grabau (1931, p. 198, pl. 16, figs. 1, 2) from the Permian of Mongolia is also comparable to the present specimen in posterior outline of the ventral valve but is different in its large size and in having broader concentric rugae. *Phricodothyris asiatica* (Chao, 1929, p. 91, pl. 11, figs. 12–14) from the Carboniferous of China is similar to *P. reticulariformis* in size and outline but differs in having broader concentric rugae with broader interspaces as well as in having a slightly shorter and narrower beak.

Order SPIRIFERINIDA Ivanova, 1972
Suborder CYRTINIDINA Carter and Johnson *in* Carter et al., 1994
Superfamily SUESSIOIDEA Waagen, 1883
Family DAVIDSONINIDAE Ivanova, 1972
Genus DAVIDSONINA Schuchert *in* Schuchert and LeVene, 1929
DAVIDSONINA? sp.
Figure 9.12–9.16

Description.—Shell small for genus, ranging from 5 to 18 mm in width and 4 to 10 mm in length, pentagonal to slightly rectangular in ventral view; hinge line straight, bearing maximum width. Ventral valve hemipyramidal, strongly convex in profile, most convex at umbo; beak acute and incurved; interarea triangular, wide and high, flat to slightly concave, extending anteriorly to about half of ventral valve; delthyrium triangular and open; sulcus distinct, originating from umbo, bounded by two lateral plications; plications strong, boardering sulcus; sulcus smooth; flanks steeply inclined laterally, ornamented with a distinct costa near sulcus and one or two weak costae at its sides; all plications and costae originating from beak; interspaces wider than costae. Ventral interior with dental plates and duplex median septum, uniting to form shallow spondylium; median septum extending to anterior margin, highest beneath spondylium and lower anteriorly; muscle scars not observed.

Material.—A ventral external mold (NMV P309879) and three ventral internal molds (NMV P309880-309882).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species has morphological characters of *Davidsonina* Schuchert (Schuchert and LeVene, 1929), including the high interarea and the structures of the ventral interior (spondylium and median septum). However, it is smaller and has fewer costae with a smooth sulcus, unlike that seen in any other species of *Davidsonina*. *Cyrtina* Davidson, 1859 *in* 1858–1863, the oldest genus (Devonian) in the cyrtiniform punctuate spiriferids and also a genus from the Cyrtinoidea bearing the closest similarity to Suessioidea, is also similar to the present species in its overall external form and ornament, but it differs in having a pseudodeltidium covering the delthyrium. Nevertheless, it is likely that the present species might represent a morphological transitional form between Cyrtinoidea and Suessioidea.

Suborder SPIRIFERINIDINA Ivanova, 1972
Superfamily PENNOSPIRIFERINOIDEA Dagys, 1972b
Family PUNCTOSPIRIFERIDAE Waterhouse, 1975
Genus PUNCTOSPIRIFER North, 1920
PUNCTOSPIRIFER? sp.
Figure 9.17–9.18

Description.—Shell of moderate size for genus, greatest width at hinge line; outline transversely elliptical; cardinal extremities subangular; anterolateral margins broadly rounded. Ventral valve slightly convex in profile, but compressed, most convex at umbonal region; interarea high, but low in juvenile specimens, transversely striated by weak lamellae; sulcus wide, distinct, smooth, originating from umbo; flanks nearly flat, with five or six strong plications; plications narrower and lower laterally, starting from umbonal region; crests of plications relatively sharp, troughs slightly wider; punctae regular in size and normally spaced (30 to 40 punctae in 1 mm^2); growth laminae not observed.

Material.—Two incomplete ventral external molds with flattened interarea (NMV P309883, 309884).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—The ovate-rectangular outline, strong plications with sharp crests, and punctae pattern shown in this species are similar to those of *Punctospirifer* North, 1920. However, it is difficult to assess its specific status due to partial preservation and distortion of the present specimens.

Family SPIRIFERELLINIDAE Ivanova, 1972
Genus SPIRIFERELLINA Frederiks, 1924
SPIRIFERELLINA sp.
Figure 9.19–9.23

Description.—Shell moderate for genus, about 11 mm wide and 8 mm long in largest ventral valve; outline slightly transverse, tending to be elongated with growth, widest at slightly anterior to hinge line; cardinal extremities subangular. Ventral valve slightly convex in profile but compressed, most convex at umbonal region; interarea relatively low but poorly preserved; sulcus relatively narrow and smooth, starting from near beak; flanks with 3–4 subangular plications; interspaces rounded, wider than plications; concentric growth laminae irregularly distributed but closely spaced at valve margin; punctae irregular in size and closely spaced in whole valve (50 to 60 punctae in 1 mm^2). Dorsal valve with angular narrow fold; other ornamentations similar to those of ventral valve. Ventral interior with dental adminicula and median septum; dental adminicula short and slightly divergent; median septum long and high. Dorsal interior bearing divergent crural plates.

Material.—Three ventral internal molds (NMV P309885–309887), a dorsal external mold (NMV P309888) and a dorsal internal mold (NMV P309889).

Occurrence.—Pennsylvanian (Moscovian), Korea (Taebaek).

Discussion.—This species can be assigned to *Spiriferellina* Frederiks, 1924 by its closely distributed punctae, subangular plications, and short, divergent dental adminicula and a long median septum. The present specimens are closely similar to a specimen assigned to *Spiriferina cristata* von Schlotheim figured by Ozaki (1931, p. 172, pl. 15, figs. 14a–14c) from northeast China in shell size, outline, and pattern of plications. Although Waterhouse and Piyasin (1970) mentioned that the specimen of Ozaki (1931) is close to *Spiriferellina cristata* (von Schlotheim, 1816) in its general appearance, both the present specimens and that of Ozaki (1931) are differentiated from *Spiriferellina cristata* in having lower plications with a lower sulcus and fold.

BRACHIOPOD ASSEMBLAGES AND GEOLOGIC AGE

The term "assemblage" is used here to refer to a biotic association comprising a group of species occurring in the same stratigraphic unit, and the co-occurrence of species is here interpreted to indicate their close ecological association in their original depositional environment. Thus, brachiopod assemblages, as describe below, not only have chronostratigraphic significance, they also have important paleoecological and paleoenvironmental implications.

We have recognized three brachiopod assemblages on the basis of species composition from six stratigraphic horizons in three sections (Fig. 3), all from the Pennsylvanian rocks of the Geumcheon-Jangseong Formation. The following explains the brachiopod species composition of each assemblage and reveals its age based on associated microfossils such as fusulinids and conodonts.

Choristites *Assemblage.*—The *Choristites* Assemblage consists of 16 brachiopod species belonging to 15 genera from four different stratigraphic horizons of the Gandong and Donggwang sections. They include *Buxtonia* sp., *Calliprotonia* sp., *Linoproductus* sp., *Orthotetes* sp., *Derbyia* sp., *Meekella* sp., *Rhipidomella parva* n. sp., *Stenoscisma wooi* n. sp., *Cleiothyridina* sp., *Martinia* sp., *Choristites paichingiensis*, *Choristites* sp., *Spiriferella*? sp., *Phricodothyris reticulariformis*, *Davidsonina*? sp., and *Punctospirifer*? sp. This assemblage is dominated by species of *Choristites*, which is an important genus in the Paleo-Tethys regions during the Pennsylvanian, although the abundance may be controlled by local environments and substrates.

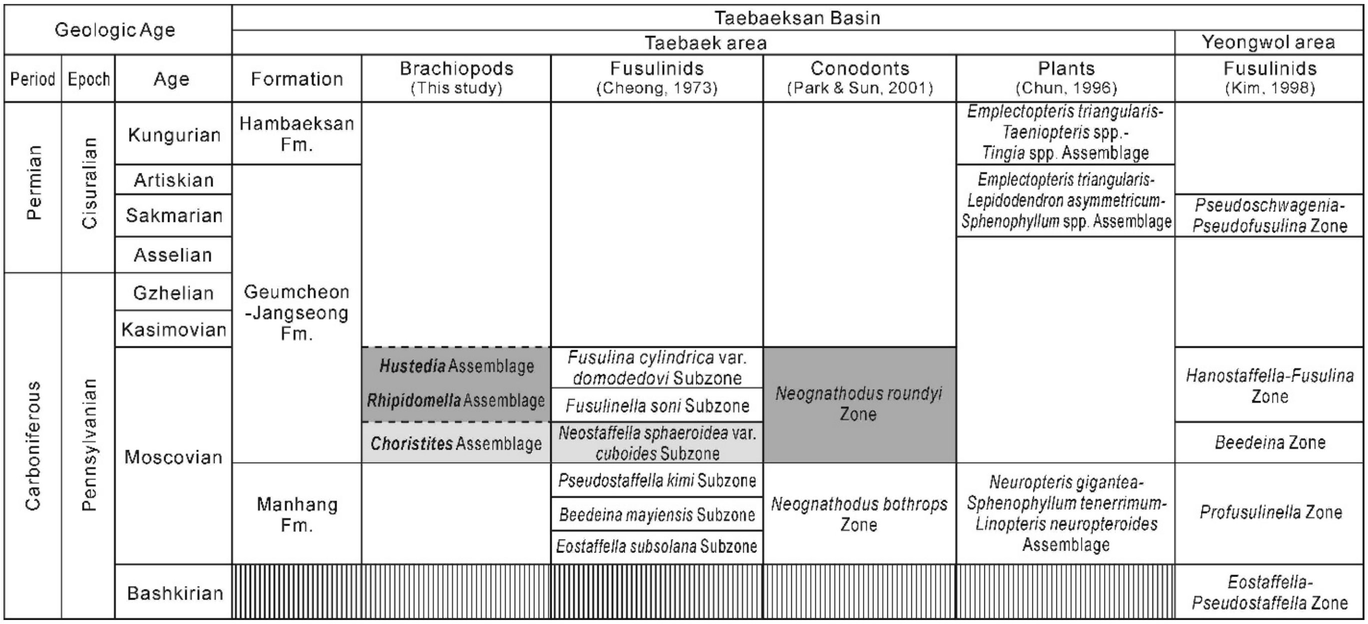
In the Gangdong section, three horizons (SD, SE, and SF) bearing the assemblage are associated with eight limestone beds (GD1-8) (Fig. 3.1), which yield fusulinids along with abundant other foraminifera and crinoid stems. (The occurrence of fusulinids from the limestone beds is displayed in Appendix 1). These fusulinids can be correlated to a fusulinid biozone suggested by Cheong (1973). The occurrence of *Neostaffella hanensis* Cheong, 1973, *N. sphaeroidea* (Ehrenberg) (Rauser-Chernousova et al., 1951), and *N. cuboides* (Rauser-Chernousova *in* Rauser-Chernousova et al., 1951) indicates that all of the fusulinid horizons from the Gangdong section belong to the *Neostaffella sphaeroidea* var. *cuboides* Subzone (Cheong, 1973). Besides, *Beedeina samarica* (Rauser-Chernousova and Belyaev *in* Rauser-Chernousova et al., 1937) and *N. sphaeroidea* in the collections can be correlated with the *Beedeina* Subzone of the Yeongwol area (Lee, 1984), *Fusulina* Zone of the Mitan area (Lee et al., 1988), *Fusulina* Zone of Japan (Niikawa, 1978), and the *Neostaffella sphaeroidea* Subzone of North China (Sheng, 1958). Cheong (1973) suggested that the *Neostaffella sphaeroidea* var. *cuboides* Subzone could be early Late Moscovian in age (Fig. 10). It is noted that *Beedeina* Galloway, 1933 and *Neostaffella* Miklucho-Maclay, 1959 have been known to be abundant in the Moscovian.

In the Donggwang section, the horizon (MN) bearing the *Choristites* Assemblage is overlain by a limestone lens (MNL) (Fig. 3.3). The limestone lens yields a few fusulinids that also occur in the Gangdong section (See Appendix 1). The occurrence of *Neostaffella sphaeroidea* suggests that the fusulinids belong to the *Neostaffella sphaeroidea* var. *cuboides* Subzone (Fig. 10; Cheong, 1973).

Rhipidomella *Assemblage.*—The *Rhipidomella* Assemblage is composed of *Breileenia radiata*, *Reticulatia*? sp., *Rhipidomella parva*, *Rhipidomella* sp. A, *Rhipidomella* sp. B, and *Alispirifer* sp. All specimens of the assemblage were collected from the MGL horizon of the Jangseong section (Fig. 3.2). This assemblage is distinguished by the absence of species of *Choristites* and a relatively high diversity of *Rhipidomella* species.

The brachiopod assemblage can be dated as late Moscovian based on the associated conodonts of the *Neognathodus roundyi* Zone (Fig. 10; Park and Sun, 2001). The *Neognathodus roundyi* Zone has been correlated with the *Neognathodus medadultimus–Neognathodus roundyi* Zone of North America (Merrill, 1975) and with the *Neognathodus roundyi–Streptognathodus cancellosus* Zone of North China (Ding and Wan, 1990), both having been assigned to the Desmoinesian, which is equivalent to the late Moscovian.

Hustedia *Assemblage.*—The *Hustedia* Assemblage comprises *Cleiothyridina* sp., *Hustedia paula*, *Spiriferella*? sp., and *Spiriferellina* sp. from the MG horizon of the Jangseong section (Fig. 3.2). The assemblage is characterized by association with abundant bivalves as well as by a dominance of *Hustedia paula*. Because the *Hustedia* Assemblage is not



Geologic Age			Taebaeksan Basin					
			Taebaek area					Yeongwol area
Period	Epoch	Age	Formation	Brachiopods (This study)	Fusulinids (Cheong, 1973)	Conodonts (Park & Sun, 2001)	Plants (Chun, 1996)	Fusulinids (Kim, 1998)
Permian	Cisuralian	Kungurian	Hambaeksan Fm.				*Emplectopteris triangularis*-*Taeniopteris* spp.-*Tingia* spp. Assemblage	
		Artiskian	Geumcheon-Jangseong Fm.				*Emplectopteris triangularis*-*Lepidodendron asymmetricum*-*Sphenophyllum* spp. Assemblage	
		Sakmarian						*Pseudoschwagenia*-*Pseudofusulina* Zone
		Asselian						
Carboniferous	Pennsylvanian	Gzhelian						
		Kasimovian						
		Moscovian		***Hustedia*** Assemblage	*Fusulina cylindrica* var. *domodedovi* Subzone	*Neognathodus roundyi* Zone		*Hanostaffella*-*Fusulina* Zone
				Rhipidomella Assemblage	*Fusulinella soni* Subzone			
				Choristites Assemblage	*Neostaffella sphaeroidea* var. *cuboides* Subzone			*Beedeina* Zone
			Manhang Fm.		*Pseudostaffella kimi* Subzone	*Neognathodus bothrops* Zone	*Neuropteris gigantea*-*Sphenophyllum tenerrimum*-*Linopteris neuropteroides* Assemblage	*Profusulinella* Zone
					Beedeina mayiensis Subzone			
					Eostaffella subsolana Subzone			
		Bashkirian	▥	▥	▥	▥	▥	*Eostaffella*-*Pseudostaffella* Zone

FIGURE *10*—Correlation of biotic successions (biozones or assemblages) from the Pennsylvanian and Cisuralian sequences of the Taebaeksan Basin. Dashed lines, uncertain age; vertical lined areas, intervals without strata. (Vertical length of blank for each Age does not reflect relative geologic time interval.)

associated with any limestone beds bearing microfossils, it is difficult to determine the precise age of the fauna. However, considering the age of the *Rhipidomella* Assemblage stratigraphically located below and a short interval about 3 m separating the two brachiopod assemblages (Fig. 3.2), it is reasonable to consider the age of the *Hustedia* Assemblage to be late Moscovian (Fig. 10).

The bivalve assemblage associated with the *Hustedia* Assemblage comprises abundant specimens of *Astartella* Hall, 1858 and *Aviculopecten* M'Coy, 1851, all of which can be correlated with early Pennsylvanian fauna of North China, corresponding to Serpukhovian to Moscovian age (Zhang and Yan, 1993; Yun and Yang, 1997).

Consequently, all brachiopod assemblages are assigned to late Moscovian (Fig. 10).

PALEOECOLOGY AND PALEOENVIRONMENT

Although Lee and Chough (2006a, 2006b) have recently suggested a general lagoonal setting for the Geumcheon-Jangseong Formation with pronounced lateral variations, the relationships between the environment and their faunas have yet to be established.

According to the lithological classification in the Hwangji Group by Lee and Chough (2006b), the Geumcheon-Jangseong Formation is composed of eight sedimentary facies (Table 1). In the formation, all the fossiliferous layers consist of gray homogeneous mudstone to fine sandstone (Facies Fg) that is commonly associated with bioturbated limestone (Facies Lb) (Fig. 3). The sedimentary facies Fg can be subdivided into four subfacies based on grain size: subfacies Fg1 mainly of fine sandstone, subfacies Fg2 of very fine sandstone mixed with silt grains, subfacies Fg3 of homogeneous siltstone, and subfacies Fg4 largely of claystone. Each fossil-bearing layer belongs to one of these subfacies: SE layer in the Gangdong section to the subfacies Fg1; MN layer in the Donggwang section and MGL layer in the Jangseong section to the subfacies Fg2; SF layer in the Gangdong section and MG layer in the Jangseong section to the subfacies Fg3; and SD layer in the Gangdong section to the subfacies Fg4 (Fig. 3). The correlation between the faunal composition and the subfacies can be useful not only for understanding the relationships between sedimentary environments and faunas but also for reconstructing their paleoecology. Table 2 summarizes the sedimentary and faunal characters of fossil horizons for three brachiopod assemblages.

Choristites *Assemblage*.—The *Choristites* Assemblage is recognized in three layers (SF, SD, SE) of the Gangdong section and one layer (MN) of the Donggwang section (Fig. 3.1). The SF layer of the Gangdong section (5 cm thick) consists of dark gray homogeneous siltstone (Subfacies Fg3). The layer is overlain by massive packstone to grainstone bed (GD1) and its base is in contact with a dyke. The dike intrusion caused contact metamorphism to this layer and black shale bed. The SF layer yields a low diversity of brachiopods, whereas the GD1 bed contains numerous disarticulated crinoid stems and fragments that are thought to be parts of crinoid or other echinoderms. The brachiopod assemblage of SF layer consists mainly of *Choristites paichingiensis*, *Derbyia* sp., and *Meekella* sp., but all have low abundance. *Derbyia* sp. is the dominant species in this assemblage. All brachiopod valves were disarticulated and their shells have been completely dissolved (i.e., they are preserved as molds).

The SD layer of the Gangdong section is composed of brown to black homogeneous claystone (Subfacies Fg4), which is underlain by bioturbated wackestone to packstone bed (GD4). This layer (about 5 cm thick) is partly intruded by a dike. It mainly contains abundant brachiopods and crinoid stems. Poorly preserved inarticulate brachiopods are predominant in this brachiopod assemblage. *Choristites paichingiensis*, *Meekella* sp., *Linoproductus* sp., and *Punctospirifer*? sp. also occur. Most of the brachiopod valves are disarticulated, and their axes are aligned parallel to the bedding plane.

TABLE 1—Description of sedimentary facies for the Geumcheon-Jangseong Formation (modified from Lee and Chough, 2006b).

Sedimentary Facies	Description
*Crudely cross-stratified conglomerate (**Ccd**)*	Well sorted to moderately sorted and granule- to pebble-grade clasts in moderately sorted sand to silt matrix; crudely cross-stratified or disorganized
*Crudely cross-stratified sandstone (**Scs**)*	Poorly sorted to moderately sorted and well-rounded to subrounded coarse sandstone to granule-grade conglomerate; crudely cross-stratified with discontinuous granule trains or streaks; meter-scale cross stratification sets; sharp erosional lower boundary and gradational upper boundary in some beds
*Horizontally stratified sandstone (**Sh**)*	Moderately to well sorted fine to coarse sandstone; horizontally crudely stratified; alternation of coarse sand and fine sand or discontinuous trains of well sorted granule and sand grain
*Massive sandstone (**Sm**)*	Poorly sorted to moderately sorted and rounded medium to coarse sandstone; massive; commonly, sharp planar upper and lower boundaries; gray, dark gray, yellowish gray
*Gray homogeneous mudstone (**Fg**)*	Gray fine sandstone to mudstone; massive or homogeneous; occasionally, dark gray to black mudstone chip or pyrite dispersed; partly, faintly laminated; variation in color—gray, yellowish gray, greenish gray, and milky white; marine invertebrate fossils such as brachiopod, bivalve, and crinoid in some beds
*Laminated mudstone (**Fl**)*	Fine sandstone to mudstone; in part, discontinuous and wavy laminated; occasionally finer laminae commonly reddish; partly fissile; calcareous nodule or pyrite appeared; occasionally, plant fossils contained
*Black shale (**Sb**)*	Black shale or coaly shale; partly laminated; laterally various in thickness; many plant fossils occurred
*Bioturbated wackestone to packstone (**Lb**)*	Wackestone to packstone, consisting of bluish gray matrix with bioclastic fragments such as foraminifera and crinoid; partly bioturbated; mottled texture caused by selective dolomitization of burrows; the burrows are mainly horizontal or subhorizontal and subordinately vertical; regionally wedged or lenticular in bed geometry; chert nodules or layers regionally contained

The SE layer of the Gangdong section comprises massive fine-grained sandstone about 10-cm-thick (Subfacies Fg1) and is coarsening upward. It is overlain by a bioturbated wackestone to packstone bed lacking chert nodules (GD6). The SE layer yields abundant brachiopods including *Choristites paichingiensis*, *Derbyia* sp., *Meekella* sp., *Cleiothyridina* sp., and *Spiriferella*? sp., along with disarticulated crinoid stems and bryozoans. *Choristites paichingiensis* is predominant in the brachiopod assemblage. However, *Derbyia* sp. occurs dominantly in the lower part of the SE layer composed of finer sands. Most of the brachiopod valves are disarticulated and arranged parallel to the bedding plane. Shell materials have been commonly dissolved, and they are preserved as molds.

The MN layer of the Donggwang section consists of greenish gray, very fine sandstone mixed with some silt (Subfacies Fg2) and is overlain by a lens-shaped bioturbated wackestone (MNL). This layer contains abundant brachiopods and crinoid stems. The brachiopod assemblage is composed of *Buxtonia* sp., *Calliprotonia* sp., *Orthotetes* sp., *Rhipidomella parva* n. sp., *Stenoscisma wooi* n. sp., *Cleiothyridina* sp., *Martinia* sp., *Choristites* sp., *Spiriferella*? sp., *Phricodothyris reticulariformis*, and *Davidsonina*? sp. *Stenoscisma wooi* is the most abundant species in the assemblage. Brachiopod valves are preserved as molds of articulated or disarticulated shell, whereas all of crinoid stems are disarticulated.

Lee and Chough (2006a) suggested that the Geumcheon-Jangseong Formation of the Gangdong section was deposited in subtidal environments of an open marine setting, as evidenced by thick bioturbated packstone and wackestone (Fig. 11A). The abundance of *Derbyia*, a representative genus of open-marine conditions, from SF and SE layers in the Gangdong section and disarticulated brachiopod shells support this interpretation (Gibson and Gastaldo, 1987). The *Choristites* Assemblage characteristic of this environment has brachiopods with relatively large valves, such as *Derbyia*, *Meekella*, and *Choristites* (Fig. 11.1). They presumably shared the niche with crinoids and bryozoans. The composition of each brachiopod fauna from the SF and SE layers reveals that *Derbyia* is most abundant in the SF layer, reflecting a finer-grained substrate (Subfacies Fg3), whereas *Choristites* is predominant in the SE layer representing a coarser-grained substrate (Subfacies Fg1).

In the SD layer of the Gangdong section, abrupt cessation of carbonate deposition and the appearance of an approximately 6-m-thick homogeneous black mudstone bed were a result of a transgression accompanied by a sea-level rise. The sea-level rise may have caused the establishment of a relatively oxygen-deficient environment (Wignall, 1991) and also very likely altered the nutrient composition and quantity, the latter being an important ecological determinant affecting the composition, body size and abundance of brachiopods, as recently demonstrated by Pérez-Huerta and Sheldon (2005) based on evidence from the Pennsylvanian brachiopod faunas of the Great Basin, USA. The *Choristites* Assemblage in the SD layer mainly comprises numerous inarticulate brachiopods, plus *Linoproductus*, *Meekella*, and *Punctospirifer* (Fig. 11.2). The abundance of inarticulate brachiopods, which are known to be able to survive in poorly oxygenated waters, is most likely related to the onset of a dysaerobic environment (Emig, 1997). The emergence of *Linoproductus* in this assemblage might be connected with the availability of a fine-grained substrate, considering the life habit for linoproductoid brachiopods (Muir-Wood and Cooper, 1960; Ager, 1967). Also likely to account for the dominance of inarticulate and productid brachiopods in the SD layer is that the transgression, accompanied by an increase of water depth, may have significantly reduced the food availability in the environment, which would have favored productids and suppressed spiriferid species, according to Pérez-Huerta and Sheldon (2005).

The MN layer of the Donggwang section yields the most diverse brachiopods of the *Choristites* Assemblage. It is assumed that the assemblage inhabited an environment under the influences of open marine conditions. However, the small portion of limestone in the section, coupled with the relatively small shell-size (e.g., *Stenoscisma* and *Rhipidomella* species) of

TABLE 2—Lithological and faunal characters of each fossil horizon and their inferred paleoenvironments.

Assemblage	Locality	BBLH*	Characters	Associated genera (Each bold genus is the most dominant.)	Inferred environment
Choristites Assemblage	Gandgong section	SF	Sedimentary subfacies Fg3; dark gray homogeneous siltstone overlain by limestone layer (GD1) and slightly metamorphosed by dyke intrusion. Only a few brachiopods contained, while lower part of GD1 consists of numerous grains of crinoid stems; mold state of disarticulated shells.	*Choristites*, ***Derbyia***, *Meekella*	Open shelf (Fig. 11A$_1$)
		SE	Sedimentary subfacies Fg1; massive fine sandstone overlain by limestone layer (GD6); about 10 cm in thickness. Brachiopod dominant with a few crinoid and bryozoa; *Choristites* dominant; most of shell large, disarticulated, and imbricated; preserved as mold.	***Choristites***, *Derbyia*, *Meekella*, *Spiriferella*, *Cleiothyridina*	Open shelf (Fig. 11A$_1$)
		SD	Sedimentary subfacies Fg4; brownish to black homogeneous claystone underlain by limestone (GD4), partly slaty. One species of inarticulate brachiopods dominant with numerous crinoid stems of small size; shells compressed and replaced or dissolved.	*Linoproductus*, *Meekella*, *Choristites*, *Punctospirifer*, **Unclassifiable inarticulate brachiopod**	Offshore with deficient oxygen (Fig. 11A$_2$)
	Donggwang section	MN	Sedimentary subfacies Fg2; greenish gray very fine sandstone overlain by limestone lens (MNL). Brachiopod and crinoid stems dominant; most specimens as mold; *Stenoscisma wooi* dominant; valves articulated or disarticulated, but crinoid stems disarticulated.	***Stenoscisma***, *Choristites*, *Buxtonia*, *Calliprotonia*, *Rhipidomella*, *Martinia*, *Cleiothyridina*, *Phricodothyris*, *Orthotetes*, *Spiriferella*, *Davidsonina*	Partly restricted marine where limestone deposition is possible (Fig. 11B)
Rhipidomella Assemblage	Jangseong section	MGL	Sedimentary subfacies Fg2; greenish gray very fine sandstone partly with silt grains underlain by limestone layer (JS2). Brachiopod and crinoid stems dominant; brachiopod small in size, almost preserved as mold of articulate shell; trilobite occurs.	***Rhipidomella***, *Breileenia*, *Reticulatia*, *Alispirifer* phillipsid (trilobite)	Partly restricted marine where limestone deposition is possible (Fig. 11C)
Hustedia Assemblage	Jangseong section	MG	Sedimentary subfacies Fg3; homogenous siltstone with fissility. Bivalve dominant; brachiopod, crinoid, coral, and trilobite also occur; specimens slightly compressed and preserved as mold; sometimes crinoid well-preserved with cirrus; brachiopod articulated or disarticulated.	***Hustedia***, *Punctospirifer*, *Spiriferella*, *Cleiothyridina*, *Spiriferellina* *Astartella*, *Aviculopecten* (bivalve) phillipsid (trilobite)	Restricted marine such as lagoon (Fig. 11D)

*BBLH = brachiopod-bearing lithological horizon (see Fig. 3).

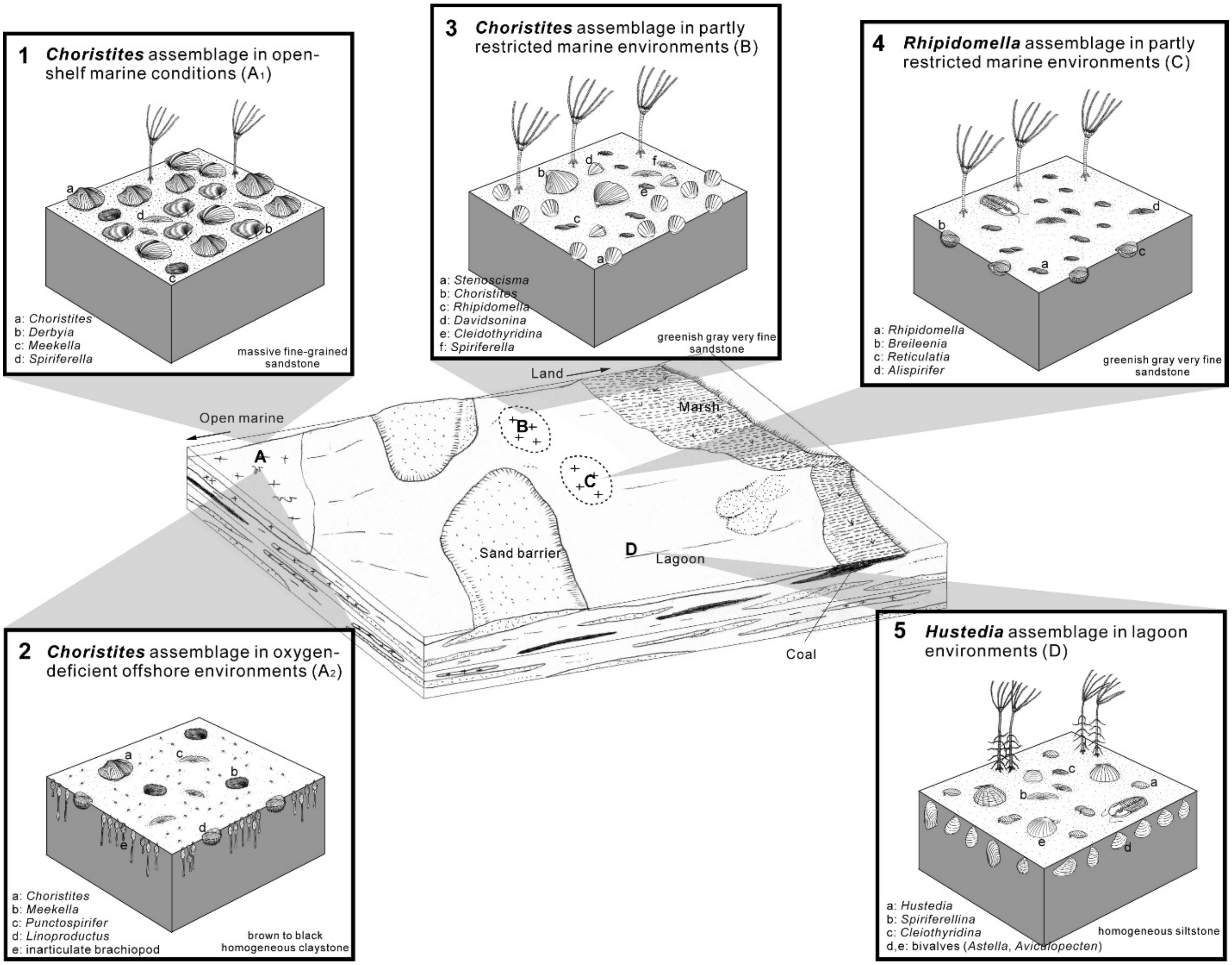


FIGURE *11*—Reconstructed depositional environments and paleoecology of the various brachiopod assemblages in the Geumcheon-Jangseong Formation. In this reconstruction, the Geumcheon-Jangseong Formation is considered to have been deposited in lagoonal (or marginal marine) environments with localized deposition of carbonate and coal (Lee and Chough, 2006a, 2006b). Bioturbated limestone and horizontal burrows are suggestive of shallow subtidal environments. Massive dark gray to black sandstone were formed in shoreface or sand barrier environments, while coal beds were deposited in the marsh. Lithologic differences between sections and compositional differences in brachiopod assemblages suggest a variety of marginal marine environments; and each brachiopod assemblage is believed to have been adapted to a particular ecological condition and depositional regime (*1–5*). *1*, *Choristites* Assemblage from SE and SF horizons of Gangdong section representing open marine setting (A_1); *2*, *Choristites* Assemblage from SD horizon of Gangdong section representing oxygen-deficient offshore setting (A_2); *3*, *Choristites* Assemblage from MN horizon of Donggwang section representing partly restricted marine setting (B); *4*, *Rhipidomella* Assemblage from MGL horizon of Jangseong section representing partly restricted marine setting (C); *5*, *Hustedia* Assemblage from MG horizon of Jangseong section representing lagoon setting (also see text and Fig. 3 for more discussion).

the brachiopods, most of which are preserved with still-conjoined valves, indicates that the brachiopods probably lived in a relatively quiet and partially restricted environment (Fig. 11). *Stenoscisma wooi* is a very abundant species of the *Choristites* Assemblage in the Donggwang section (Fig. 11.3). It is likely that this species used its thickened ventral beak for attachment to substrate.

Rhipidomella *and* Hustedia *assemblages*.—The MGL layer of the Jangseong section consists of greenish gray, very fine-grained sandstone locally mixed with silt (Subfacies Fg2). It is about 5 cm thick and underlain by bioturbated wackestone (JS2). The layer contains brachiopods, crinoid stems, and trilobites. The brachiopod fauna is composed of *Breileenia radiata*, *Reticulatia*? sp., *Rhipidomella parva*, *Rhipidomella* sp. A, *Rhipidomella* sp. B, and *Alispirifer* sp. They are predominantly small in size. Most brachiopods are preserved as molds of articulated shells.

The MG layer of the Jangseong section comprises homogeneous siltstone with weak fissility (Subfacies Fg3). The layer is not associated with any limestone bed, unlike fossil-bearing layers in the other two sections. Bivalves are predominant, while brachiopods, crinoids, gastropods, and arthropods occur occasionally (Yang et al., 1984; Yun and Yang, 1997). The bivalve assemblage mainly comprises species of *Astartella* and *Aviculopecten*. The brachiopod assemblage is composed of *Cleiothyridina* sp., *Hustedia paula*, *Spiriferella*? sp., and *Spiriferellina* sp. The brachiopod valves are partly deformed by compression and mostly articulated. The crinoid stems are articulated in most cases, and cirri are well-preserved (Lee and Chough, 2006b, fig. 7.G). The disarticulated pygidia of trilobites belong to phillipsids. Most of specimens are preserved as molds.

The absence of limestone beds except for two thin layers implies that the Geumcheon-Jangseong Formation of the Jangseong section was deposited in restricted marine environments protected by physical barriers (Fig. 11C, D). The dominance of small brachiopod species from both the MGL and MG layers in the Jangseong section and the articulated pattern of most brachiopod valves also suggest that the environment was partly isolated from an open marine condition. However, articulation of crinoid stems and the abundance of bivalves in the MG layer indicate that this layer was deposited in a more restricted and calm environment, probably a lagoon (Fig. 11D).

Living in a partly restricted marine environment, the *Rhipidomella* Assemblage consists mainly of species of *Rhipidomella* with small productoids such as *Breileenia radiata* and *Reticulatia*? sp. (Fig. 11.4). Crinoids with relatively thick stems were abundant and a few trilobites inhabited the same space. In spite of the similarity between the MGL and MN layers in physical conditions including substrate type, they exhibit very different brachiopod compositions, except for the appearance of *Rhipidomella*. The difference might have been driven by a change in food supply. Overall the tiny shell-size of brachiopods and the higher portion of productids, as displayed in the *Rhipidomella* Assemblage, would suggest a lower-nutrient setting (Pérez-Huerta and Sheldon, 2005).

The *Hustedia* Assemblage in restricted marine environments is characterized by a dominance of *Hustedia paula* and association with abundant bivalves and crinoids (Fig. 11.5). Infaunal *Astartella* and epifaunal *Aviculopecten* (Zhang and Yan, 1993; Quiroz-Barroso and Perrilliat, 1998) are dominant in the bivalve assemblage and the crinoids are composed of thin stems with several cirri. Trilobites similar to those associated with the *Rhipidomella* Assemblage also shared the niche with the *Hustedia* Assemblage.

BIOGEOGRAPHIC AFFINITIES

The Sino-Korean Block encompassing the Taebaeksan Basin was located within the northeastern Paleo-Tethyan ocean during the Pennsylvanian (Nie et al., 1990). Pennsylvanian strata comparable to that of the Taebaeksan Basin also occur in the adjacent blocks including South China, the Tarim Basin, and Indochina. Although their sedimentary environments are different from those of Taebaeksan Basin, these adjacent blocks yield comparable brachiopod assemblages.

Fan and He (1999) established a brachiopod assemblage zone from the Moscovian strata of North China: the *Brachythyrina lata–Choristites yanghukouensis–Echinoconchus elegans* Assemblage Zone from the Benxi Formation of Shanxi Province in North China. Also, Ozaki (1931) described a diverse brachiopod fauna from the same formation, characterized by numerous species of *Choristites*. The fauna is closely comparable with the *Choristites* Assemblage of Taebaek by sharing several species and genera, such as *Choristites paichingiensis*, *Meekella*, *Derbyia*, and *Stenoscisma*, and by the abundance of *Choristites*. On the other hand, the *Chonetes sarcinulatus–Chonetinella lata* Assemblage of Fan and He (1999) from the Kasimovian to Gzhelian of North China is not comparable with any faunas from the Geumcheon-Jangseong Formation.

In the Pennsylvanian strata of South China, Jin and Liao (1987) recognized the *Choristites mansuyi–Semicostella panxianensis* and *Buxtonia grandis* Assemblages representing the Bashkirian and Moscovian, respectively. Though the abundance of *Choristites* in the *Choristites mansuyi–Semicostella panxianensis* Assemblage is comparable to the *Choristites* Assemblage of Taebaek, other constituents of this assemblage are not known in the assemblages of the Taebaeksan Basin. The succeeding *Buxtonia grandis* Assemblage does not share any species with the assemblages of the Geumcheon-Jangseong Formation.

In the Tarim Basin in northwest China, Chen (2004) proposed three Pennsylvanian brachiopod zones, namely the early Moscovian *Choristites abnormalis* Zone, late Moscovian *Purdonella artuxensis* Zone, and the Kasimovian to Gzhelian *Linoproductus cora* Zone. None of these faunas show any particular affinities with the assemblages from the Geumcheon-Jangseong Formation except for the abundance of *Choristites*.

Yanagida (1975) described a Moscovian brachiopod fauna from northern Thailand composed of 19 species belonging to 16 genera. Among them, *Rhipidomella*, *Derbyia*, *Punctospirifer*, *Martinia*, *Phricodothyris*, and *Stenoscisma* are also documented in the *Choristites* Assemblage of the Geumcheon-Jangseong Formation. However, the Thailand fauna is distinct from the *Choristites* Assemblage in the paucity of *Choristites*.

In conclusion, the *Choristites* Assemblage of the Taebaeksan Basin shows a strong biogeographic link with the Moscovian fauna of North China. Although *Choristites* is regionally widespread in the Paleo-Tethys regions including North China (Fan and He, 1999; Ozaki, 1931), South China (Jin and Liao, 1987), the Tarim Basin (Chen, 2004), and also in the Moscow Basin (Sarytcheva and Sokolskaya, 1952), *Choristites* species from the Taebaeksan Basin are mostly allied to those of North China. However, several species of the *Choristites* Assemblage first occur in the Cisuralian strata of North China (Fan and He, 1999), for example, *Phricodothyris reticulariformis*, *Rhipidomella*, *Buxtonia*, *Punctospirifer*, and *Martinia*. These faunal differences were presumably caused by regional and local paleoecological controls.

The *Rhipiomella* and *Hustedia* Assemblages from the Geumcheon-Jangseong Formation are relatively poor in species diversity and abundance. In addition, they are represented mostly by endemic taxa. Therefore, it is difficult to compare these faunas with those of other regions for biogeographical purpose. Nevertheless, it is worth noting that some species of these assemblages, including *Breileenia radiata*, *Hustedia paula*, and *Alispirifer* sp., show some affinities with the older species of Gondwana and western Paleo-Tethys. *Breileenia radiata* is common in the Visean of England (Brunton and Lazarev, 1997), and *Hustedia paula* and *Alispirifer* sp. were common in the southern part of Gondwana during Visean to Bashikirian times (Campbell, 1961; Maxwell, 1964; Roberts et al., 1976; Nazer, 1977). In this regard, it is possible that the Taebaeksan Basin might be a small refugium for these species, as a result of northward migration driven by the global cooling through the late Mississippian-Pennsylvanian.

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APPENDIX *1*—Fusulinids from each limestone bed of the Geumcheon-Jangseong Formation

Limestone bed (see also Fig. 3)	Fusulinids		Characteristics
GD1	*Ozawainella turgida* Sheng *O. magna* Sheng *Taizehoella taizehoensis* Sheng *Neostaffella cuboides* Rauser *N. hanensis* Cheong	*Pseudostaffella paracompressa* Safonova *P. antiqua* (Dutkevich) *Beedeina samarica* (Rauser-Chernoussova) *Eostaffella lijudmilae* Rauser-Chernoussova	Occurrence of abundant foraminifera and crinoid stems
GD2	*Ozawainella turgida* Sheng *Beedeina paradistenta* Safonova *Beedeina* sp.	*Pseudostaffella antiqua* (Dutkevich) *Fusulinella provecta* Sheng	Occurrence of abundant foraminifera
GD3	*Ozawainella* sp. *Taizehoella taizehoensis* Sheng *Eostaffella ikensis* Vissarionova *Pseudowedekindellina prolixa* Sheng	*Pseudostaffella paracompressa* Safonova *Beedeina samarica* (Rauser-Chernoussova) *Beedeina* sp. *Schubertella obscura* Lee & Shen	
GD4	*Beedeina lanceolate* (Lee & Chen) *B. acuta* (Lee) *B. samarica* (Rauser-Chernoussova) *Beedeina* sp.	*Neostaffella cuboides* Rauser *N. hanensis* Cheong *Fusulinella bocki intermedia* (Rauser-Chernoussova) *Fusulinella* sp.	Occurrence of abundant foraminifera
GD5	*Ozawainella turgida* Sheng *Neostaffella cuboides* Rauser *N. hanensis* Cheong	*Pseudostaffella paracompressa* Safonova *P. antiqua* (Dutkevich) *Pseudofusulina* sp.	Occurrence of some foraminifera
GD6	*Ozawainella magna* Sheng *Beedeina paradistenta* Safonova *Beedeina* sp.	*Pseudostaffella paracompressa* Safonova *P. antiqua* (Dutkevich) *Fusulinella bocki intermedia* (Rauser-Chernoussova) *Fusulinella* sp.	Occurrence of foraminifera of large size
GD7	*Beedeina* sp. *Schwagerina campa* Thomson	*Neostaffella sphaeroidea* (Ehrenberg) *Fusulina similis* Gryzlova	Large in size
GD8	*Ozawainella turgida* Sheng *O. magna* Sheng	*Pseudostaffella kimi* Cheong	
MN	*Neostaffella sphaeroidea* (Ehrenberg)	*Ozawainella* sp.	Large in size