

# Where art thou “the great hiatus?” – review of Late Ordovician to Devonian fossil-bearing strata in the Korean Peninsula and its tectonostratigraphic implications

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**ABSTRACT:** We review paleontologic evidence from the Upper Ordovician to Devonian strata in the Korean Peninsula and discuss their tectonostratigraphic origin. The Upper Ordovician–Devonian fossil-bearing strata are largely distributed in North Korea, and tectonostratigraphically in the southern margin of the Pyeongnam Basin and in the northern part of the Imjingang Belt. The fossils have been regarded as evidence that the “great hiatus” of the middle Paleozoic is not a prevalent phenomenon across the Sino-Korean Block. Examination of selected fossils with stratigraphic and paleogeographic significance reveals that the fossils from the Sangsori, Koksan and Wolyangri series and the Rimjin System are of the Late Ordovician to Devonian and display affinity to those of the coeval strata of South China. In addition, the fossils included within clasts of the Songrim Conglomerate, the basal unit of the Jurassic Taedong System, are of the Silurian to Devonian, which also display affinity to South China. The faunal and floral affinity suggests that the Upper Ordovician to Devonian strata in North Korea most likely formed in a basin(s) of or peripheral to the South China Block, which indicates that the strata are allochthonous, contrary to the traditional interpretation of their autochthonous origin by North Korean geologists. The Permo-Triassic collision between the two Chinese cratons which resulted in the amalgamation of three massifs of the Korean Peninsula is considered to be responsible for the accretion and juxtaposition of the Upper Ordovician to Devonian strata onto the Sino-Korean Block. The autochthonous origin of the strata suggests the absence of the “great hiatus” at least in North Korea, whereas the allochthonous origin its presence across the Sino-Korean Block.

**Key words:** Middle Paleozoic strata, Korean Peninsula, paleontologic evidence, Sangsori, Koksan and Wolyangri series, Rimjin System

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## 1. INTRODUCTION

The Paleozoic strata in the Korean Peninsula are distributed in the Pyeongnam and Taebaeksan basins (Figs. 1 and 2) in which Japanese geologists designated the lower Paleozoic Joseon and upper Paleozoic Pyeongan systems (Tateiwa, 1926; Kawasaki, 1927; Kobayashi, 1933; Shiraki, 1940; Yosimura, 1940; Aoti, 1942). Since Willis et al. (1907) first noted the existence of a “great

hiatus” between the lower and upper Paleozoic strata across northern China, subsequent studies confirmed the absence of middle Paleozoic strata in the Sino-Korean Block, but its presence in the South China Block (see Meyerhoff et al., 1991 for references).

In the 1930s, Japanese geologists reported occurrences of middle Paleozoic fossils in the Pyeongnam Basin, challenging the notion of the middle Paleozoic “great hiatus” in the Sino-Korean Block (Shimamura, 1929; Kobayashi, 1930; Shimizu et al., 1934; Kobayashi, 1935; Yabe and Sugiyama, 1937). The importance of these discoveries was not fully appreciated until additional findings were made in North Korea during the 1970s and 1980s. Based on these findings, North Korean geologists designated the Hwangju System as a chronostratigraphic unit in the Pyeongnam Basin that includes the Silurian strata as well as

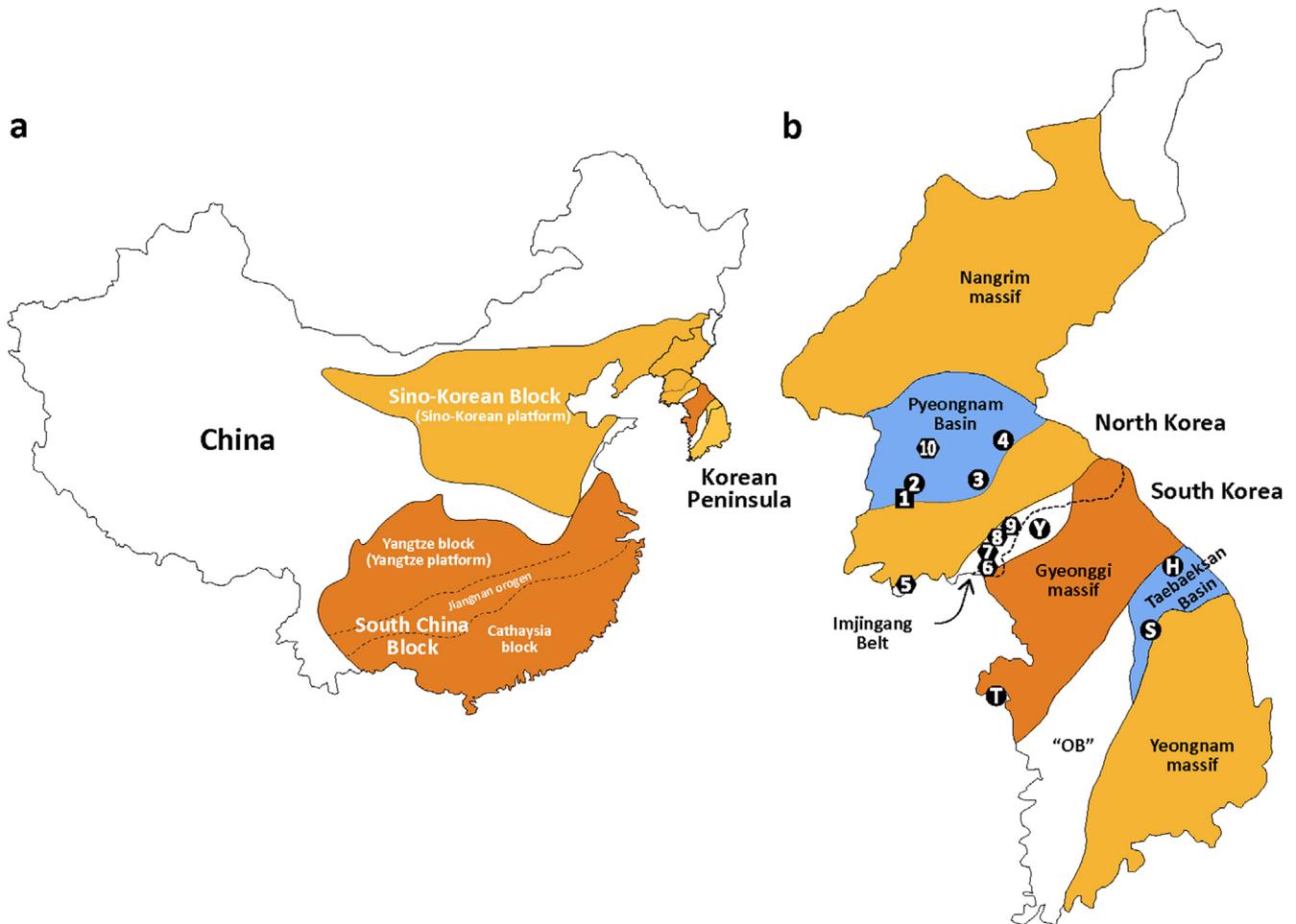
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**Fig. 1.** (a) Tectonic map of China and Korean Peninsula modified after Zheng et al. (2013, figs. 2, 3, 5). (b) Localities of the strata where the Late Ordovician to Devonian fossils occur and those of which the age is determined to be middle Paleozoic by zircon geochronology. 1, Songrim Conglomerate in the Songrim area (Fig. 3c); 2, Sangsori Series in the Hwangju-Songrim area (Figs. 3a and c); 3, Sangsori and Koksan Series in the Suan-Koksang-Singye area (Figs. 3a and d); 4, Sangsori and Koksang Series in the Poptong area (Figs. 3a and b); 5, Rimjin System in the Kangryong area (Fig. 4); 6–9, Rimjin System in the Kumchon and Cheolwon area (Fig. 4); 10, Possible Rimjin System in the Seungho area; Y, Yeoncheon complex; T, Taean Formation; H, Hoedongri Formation in the Jeongseon area; S, Sapyongri Conglomerate in the Danyang area. “OB” is the Okcheon Metamorphic Belt or Okcheon Basin; the areal extent of the Imjingang Belt is modified from Ree et al. (1996, fig. 1) and Cho et al. (2007, fig. 1); the Nangrim and Yeongnam massifs are regarded as part of the Sino-Korean Block and the Gyeonggi massif as part of the South China Block (Chough et al., 2000; Chough, 2013; Choi, 2014), although there are different opinions on their tectonic affinity to the two blocks (Jeong and Lee, 2000; Oh, 2006; Oh and Kusky, 2007; Zhai et al., 2007; Kwon et al., 2009).

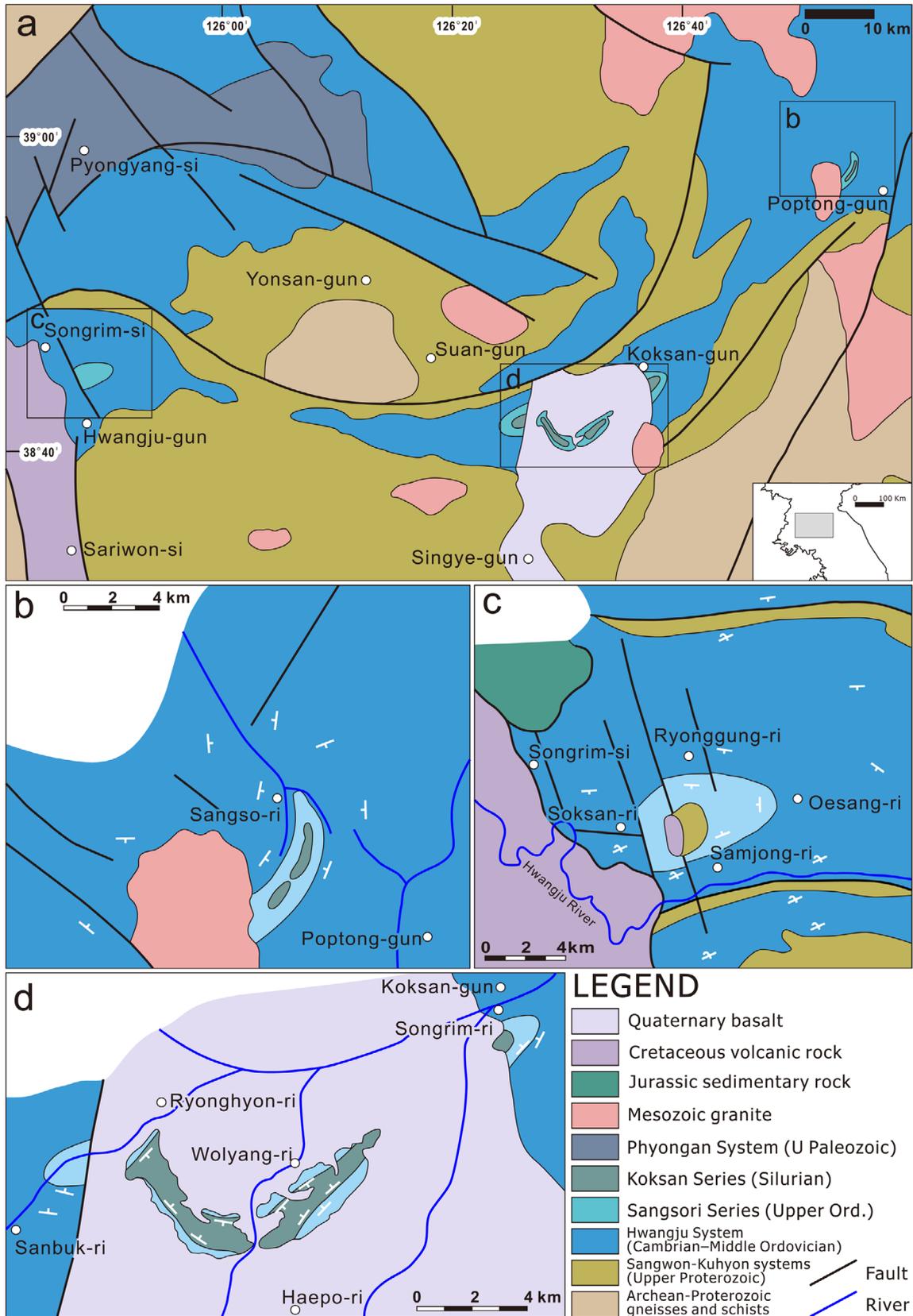
the lower Paleozoic Joseon System, and the Rimjin System as a Devonian unit in the Imjingang Belt (Pak, 1986; Pak and Kang, 1987; Ryu and Ri, 1994; Om et al., 1996; Fig. 2). It was noted that the middle Paleozoic fossil assemblages display similarity to those of the Yangtze region of the South China Block (e.g., Shimizu et al., 1934; Pak, 1976, 1984, 1986; Pak and Kang, 1987; Pak, 1996), contrary to the fact that the Cambrian to Middle Ordovician assemblages of the Korean Peninsula are assignable to the Sino-Korean platform fauna (Kobayashi, 1966a, b, 1967). North Korean geologists did not interpret such important faunal and floral disparities from a plate tectonic perspective, and accordingly interpreted the Hwangju System as an autochthonous unit, suggesting that the “great hiatus” is absent at least in North

Korea.

The biostratigraphic and paleobiogeographic significance of the Late Ordovician to Devonian fossils in North Korea has seldom received attention. Recently, Lee et al. (2013a, b) and Choi et al. (2015) compiled the occurrences of these North Korean fossils and provided tectonostratigraphic implications of the selected fossils with stratigraphic and paleogeographic significance. This paper aims to summarize and introduce the paleontologic findings in the Pyeongnam Basin and Imjingang Belt to the international community, and discuss their implications for the understanding of tectonic evolution of the Korean Peninsula and adjacent regions.

Geographic or tectonic area		Sino-Korean Block		South China Block
		Taebaeksan Basin	Pyeongnam Basin	
Geologic age		Taebaek-Samcheok area	Hwangju-Poptong area	Yeoncheon-Imjingang area
Jurassic			<b>Taedong System (Songrim Conglomerate)</b>	
		Bansong Group		
Triassic				
Permian		Pyeongnan Supergroup	Phyongan System	
Carboniferous				
Devonian				<b>Rimjin System (Yeoncheon System)</b>
Silurian				
Ordovician	Upper		Hwangju System	<b>Wolyangri Series</b> <b>Koksan Series</b>
	Middle	Taebaek Group (Joseon Supergroup)		<b>Sangsori Series</b>
	Lower			Duwibong Fm.
Jigunsan Fm.			Singok Series	
Cambrian	Furongian		Makgol Fm.	Kophung Series
			Dumugol Fm.	
	Series 3		Dongjeom Fm.	Mujin Series
		Hwajeol Fm.		
Series 2	Sesong Fm.	Hukgyo Series		
	Daegi Fm.			
Terreneuvian		Myobong Fm.	Junghwa Series	
		Jangsan/Myeonsan fms.		
Precambrian				Okcheon Group
		Yeongnam Massif	Nangrim Massif	Gyeonggi Massif

**Fig. 2.** Comparative stratigraphic summary of the Paleozoic–Mesozoic strata in South and North Korea (modified after Om et al., 1996 and Choi and Chough, 2005). The Late Ordovician to Devonian fossil-bearing stratigraphic units in North Korea are shaded. English translation of stratigraphic and tectonic province names in literatures in South and North Korea correspond to each other as follows; Yeongnam = Ryongnam, Nangrim = Rangrim or Rangnim, Gyeonggi = Kyonggi, Pyeongnam = Phyongnam, Joseon = Chosun, Pyeongan = Phyongan, Imjin = Rimjin, and Daedong = Taedong.



**Fig. 3.** Geologic map of the Upper Ordovician and Silurian outcrops in the Pyeongnam Basin. (a) Distribution of the outcrops; geologic map is modified after Om et al. (1996) and rectangular areas magnified in (b)–(d) are modified after Ham (1982) and Lee et al. (2013b, figs. 1, 3–5). (b) The outcrop near Poptong area. (c) The outcrop near Hwangju-Songrim area; very small outcrops of the Songrim Conglomerate (Lee et al., 2013a, fig. 1) are exposed in the area of ‘Jurassic sedimentary rock’ in the northwest corner. (d) The outcrop near Suan-Koksan-Singye area.

## 2. STRATIGRAPHIC NOMENCLATURE IN NORTH KOREA

In most stratigraphic schemes and geologic maps, North Korean geologists primarily employed chronostratigraphic units such as 'System' or 'Series,' which is defined as "bodies of rock formed during the same spans of time," instead of lithostratigraphic units such as 'Group' or 'Formation' which is based solely on "lithic characteristics and their relative stratigraphic position" (Murphy and Salvador, 1999). In this respect, a special attention must be paid when referring to the North Korean stratigraphic schemes. In two representative articles that summarize geology and stratigraphy of North Korea (Ryu and Ri, 1994; Om et al., 1996), the usage of stratigraphic units is confusing. For example, Ryu and Ri (1994) described the Devonian strata as the Rimjin 'Group,' whereas Om et al. (1996) designated the same unit as the Rimjin 'System'; the Sangsori Series is divided into the 'lower formation' and 'upper formation' in both literatures. This indicates that the middle Paleozoic sedimentary strata were initially defined as chronostratigraphic units based on paleontologic evidence, not taking into account of lithologic characters. We consider that without sedimentologic and structural re-examination of the sections described by the North Korean geologists, the chronostratigraphic units they erected cannot be directly re-

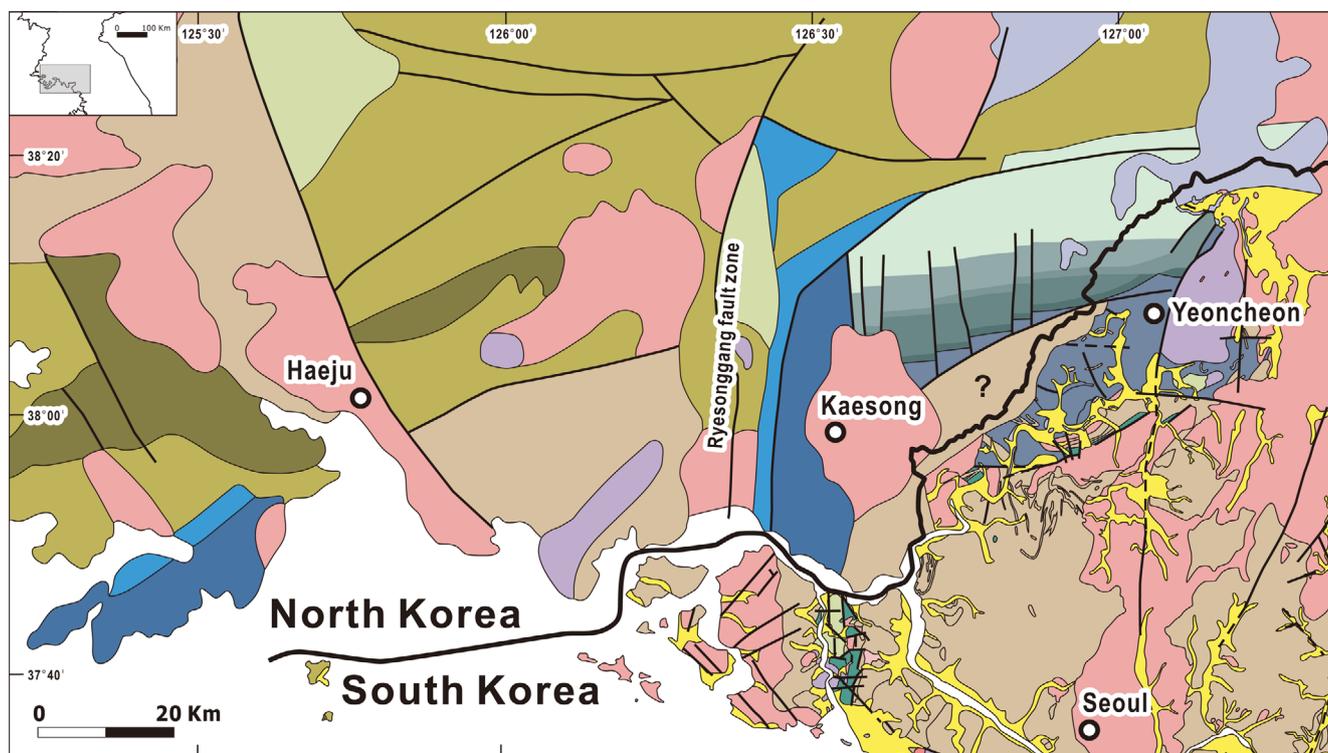
designated as lithostratigraphic units, as such revision should follow strict procedures outlined by international stratigraphic guide (Murphy and Salvador, 1999, section 3B). In this regard, we follow the chronostratigraphic units summarized in Om et al. (1996) as the representative of the North Korean stratigraphic nomenclature in the present study.

## 3. LATE ORDOVICIAN TO DEVONIAN FOSSILS IN NORTH KOREA

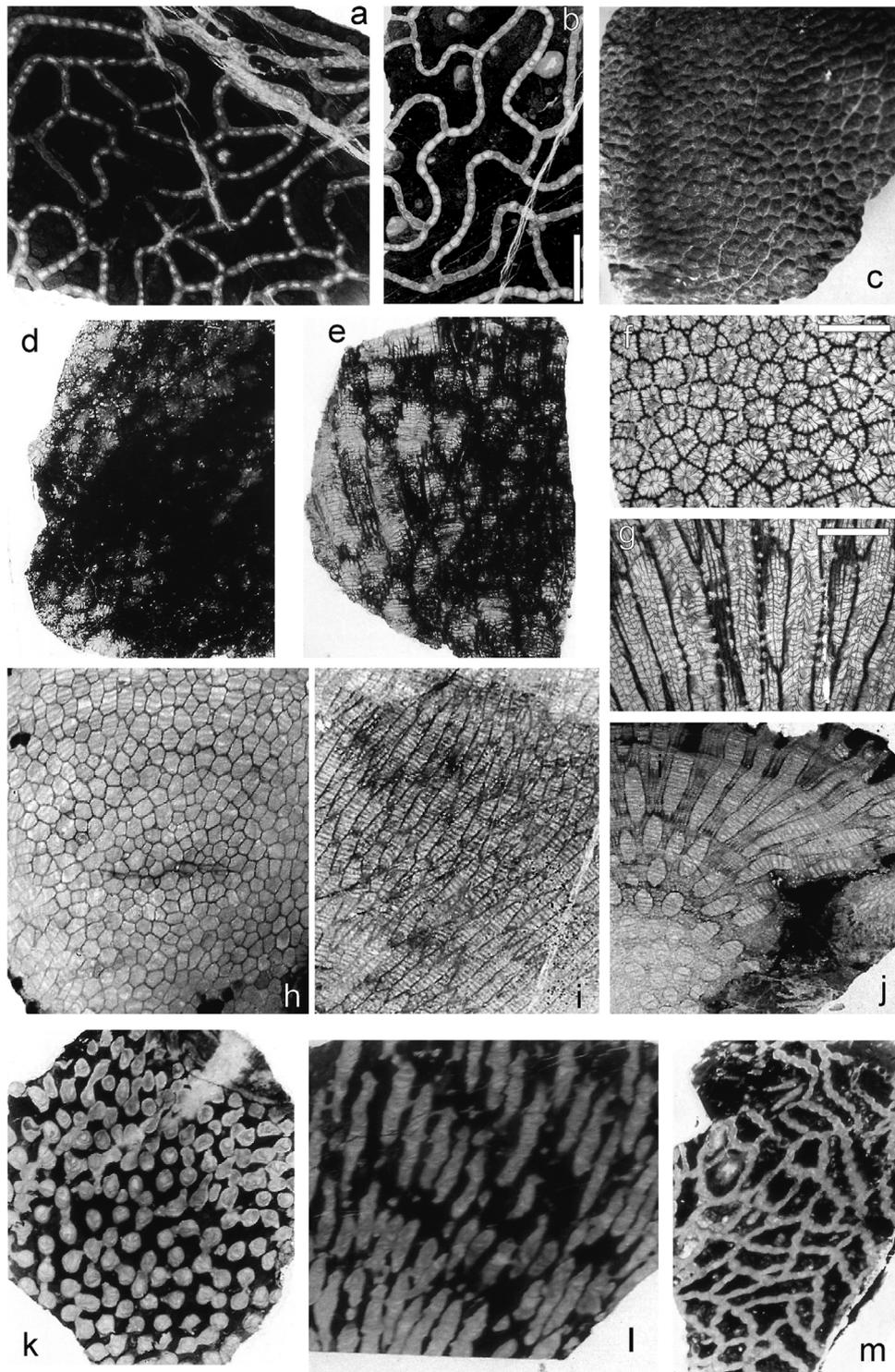
Late Ordovician to Devonian fossils occur in the Sangsori, Koksan and Wolyangri series, Rimjin System, and Songrim Conglomerate. The Sangsori, Koksan and Wolyangri series are exposed along the southern margin of the Pyeongnam Basin, in the Hwangju-Songrim, Suan-Koksan-Singye, and Poptong areas (Figs. 1 and 3); the Rimjin System is distributed within the Imjingang Belt, in the Kangryong, Kumchon, and Cheolwon areas (Figs. 1 and 4); and the Songrim Conglomerate is exposed in the Songrim area (Figs. 1 and 3).

### 3.1. Sangsori Series

The Sangsori Series overlies the Middle Ordovician Mandal Series and underlies the Koksan and Wolyangri series (Ryu and



**Fig. 4.** Distribution of the Devonian Rimjin System in the central Korean Peninsula (modified after Choi et al., 2015, fig. 1). Geologic map of North and South Korea are modified after Om et al. (1996) and Lee et al. (1999), respectively. Detailed geologic map of the Rimjin System in North and South Korea is modified after Yamaguchi (1951), Ree et al. (1996) and Kim et al. (2000). Yeochek, Jingok and Samgot units are part of the Rimjin System which experienced differential metamorphism; darker color corresponds to higher grade metamorphism (cf. Yamaguchi, 1951; Ree et al., 1996).



**Fig. 5.** Corals in the Sangsori and Koksan series in North Korea and the same species from South China. Corals of (a), (c)–(e), and (h)–(m) are figured in Hong et al. (1997) where those of (a) and (c)–(e) are described as Ordovician fossils and those of (h)–(m) as Silurian fossils. Although their stratigraphic occurrences were not specified, it is most likely that corals of (a) and (c)–(e) are from the Sangsori Series and those of (h)–(m) from the Koksan Series (cf. Fig. 2). No scale was given for each figure in Hong et al. (1997). (a) *Catenipora* sp. assignable to *C. shiyangensis*; transverse thin section showing characteristic elongated shape of lacunae. (b) *C. shiyangensis* from the Upper Ordovician Xiazhen Formation, Jiangxi Province of China (Liang et al., 2016, fig. 13-4); this species is one of the most common chain corals, endemic to southeastern China; scale bar = 5 mm. (c) Upper surface of *Agetalites*. (d and e) *Agetalites* sp. assignable to *A. yushanensis*; (d) Transverse thin section; (e) Vertical thin section. (f and g) *Agetalites yushanensis* from the Xiazhen Formation (Sun et al., 2016, figs. 5A and B), scale bar = 5 mm; (f) Transverse thin section; (g) Vertical thin section; this species is also one of the most common agetolitids, endemic to southeastern China. (h and i) *Paleofavosites* sp.; (h) Transverse thin section; (i) Vertical thin section. (j) *Heliolites* sp., vertical thin section. (k and l) *Syringopora* sp.; (k) Transverse thin section; (l) Vertical thin section. (m) '*Quepora*' (= *Catenipora*) sp., vertical thin section.

**Table 1.** Summary of global stratigraphic range of tabulate corals occurring from the Sangsori and Koksan series and Songrim Conglomerate in North Korea

Stratigraphic unit	General name	Taxonomy	Age												
			Ordovician			Silurian			Devonian			Carboniferous			
			L	M	U	Ll	W	Lu	P	L	M	U	Miss	Penn	
Clasts of Songrim Conglomerate/ Koksan Series	Coral	Favositidae	█												
			<i>Paleofavosites</i>	█											
			<i>Favosites</i>	█											
		Halysitidae	<i>Catenipora</i>	█											
		Heliolitidae	<i>Heliolites</i>	█											
		<i>Propora</i>	█												
	Syringoporidae	<i>Syringopora</i>	█												
Sangsori Series	Coral	Agetolitidae	<i>Agetolites yushanensis</i>	█											
		Tetratiidae	<i>Rhabdotetradium nobile</i>	█											
		Columnaridae	<i>Favistella</i>	█											
		Halysitidae	<i>Catenipora Zhejiangensis</i>	█											
		Halysitidae	<i>Catenipora shiyangensis</i>	█											

"G" denotes the taxa showing strong endemism.

**Table 2.** Summary of global stratigraphic range of fossils from the Rimjin System

Stratigraphic unit	General name	Species	Age						
			Silurian		Devonian			Carboniferous	
			L	M	U	Miss	Penn		
Charophyte		<i>Sycidium anhuaense</i>	█						
		<i>Sycidium reticulatum</i>	█						
		<i>Sycidium melo</i> var. <i>pskowensis</i>	█						
Brachiopod		<i>Yunnanellina triplicata</i>				█			G
		<i>Tenticospirifer vilis</i> var. <i>Kwangsiensis</i>				█			
		<i>Eoreticularis maureri</i> var. <i>altirhychus</i>				█			
Rimjin System	Terrestrial plant	<i>Arthyris hudlestoni</i> var. <i>sinensis</i>				█			
		<i>Arthyris gurdoni</i> var. <i>trasversalis</i>				█			
		<i>Leptophloeum rhombicum</i>				█			G
	<i>Hamatophyton verticillatum</i>				█			G	
Terrestrial plant		<i>Psilophyton princeps</i>	█						
		<i>Protopteridium minutum</i>	█						
		<i>Asterocalamites scrobiculatus</i>				█			
Ostracod		<i>Sublepidodendron shimenense</i>				█			
		<i>Cavellina devoniana</i>				█			
		<i>Bairdia dushanensis</i>				█			
	<i>Knoxia compressa</i>				█				

"G" denotes the taxa showing strong endemism.

Ri, 1994; Om et al., 1996; Fig. 2). Diverse corals occur in the strata (Lee et al., 2013b, table 1; Fig. 5, Table 1), some of which are particularly useful in determining the age of strata and paleobiogeographic affinity of the fauna.

The Sangsori Series consists of the lower dolostone and upper limestone units in which *Agetolites*, *Favistella*, *Catenipora*, *Rhabdotetradium* and *Heliolites* occur (Lee et al., 2013b, Table 1). *Rhabdotetradium nobile* of the lower unit and *Agetolites* of the upper unit are the highly reliable age indicator for the Late Ordovician (Sokolov, 1950; Hill, 1981; Ham, 1982; Lin and Wang,

1987; Lee et al., 2013b; Sun et al., 2016). *Agetolites* has been reported in Central Asia, South China and Tarim, and is regarded as a highly endemic taxon (Lee et al., 2013b; Sun et al., 2016). The *Agetolites* species of the Sangsori Series are identical or remarkably similar to those of the Upper Ordovician Xiaozhen and Sanqushan formations in the Yangtze platform (Pak, 1983a, b; Sun, 2011; Sun et al., 2016; Figs. 5c–g). This suggests that the Sangsori coral fauna is biogeographically closely linked to those of the platform at species level (Lin, B.Y., 1983; Lee et al., 2013b). Lee et al. (2013b) regarded *Catenipora zhejiangensis*, *Favistella*

and *Rhabdotetradium* as further indicators for the close paleobiogeographic affinity between the Sangsori and Yangtze platform fauna.

### 3.2. Koksan and Wolyangri Series

The fossil assemblage of the Koksan Series is predominated by tabulate corals, and the favositids occupy more than 60% of the coral assemblage (Lee et al., 2013b, Table 2). The coral assemblage is remarkably similar to those occurring in the clasts of the Songrim Conglomerate (Lee et al., 2013a, table 2; Table 1). Pak (1985b) suggested that the age of the Koksan corals ranges from the early to early late Silurian. Lee et al. (2013b) confirmed the Silurian age of the Koksan coral assemblage based on the absence of *Agetolites* (the diagnostic Late Ordovician coral; Hill, 1981) and *Squameofavosites* and *Parastriatopora* (the common post-Silurian corals; Hill, 1981). The Koksan and Songrim coral faunas are comparable with the Silurian (Llandovery) coral fauna of Guizhou and Sichuan provinces of South China (Pak, 1985a, b; An and Ma, 1993; Lee et al., 2013a, b), indicating a close biogeographic affinity of these Silurian coral faunas. The Llandovery tabulate coral fauna of the South China, which is restricted to the Yangtze block, is regarded as highly endemic at generic level (Rong and Chen, 2003).

The Wolyangri Series was recognized as the upper Silurian strata separated from the lower Silurian Koksan Series (Ryu and Ri, 1994; Om et al., 1996). Along with the various species of tabulate (*Favosites*, *Halysites* and *Heliolites*) and rugose (*Cystiphyllum* and *Tryplasma*) corals, fossils indicative of the early late Silurian age such as cephalopods, gastropods and crinoids also occur in the Wolyangri Series in the Sangsori area (Om et al., 1996). The *Retziella* brachiopod fauna, which is diagnostic to the late Silurian (Rong et al., 1995), is known to occur in the Wolyangri Series (Yang, 1989; An and Ma, 1993; Rong et al., 2003; Rong and Chen, 2003).

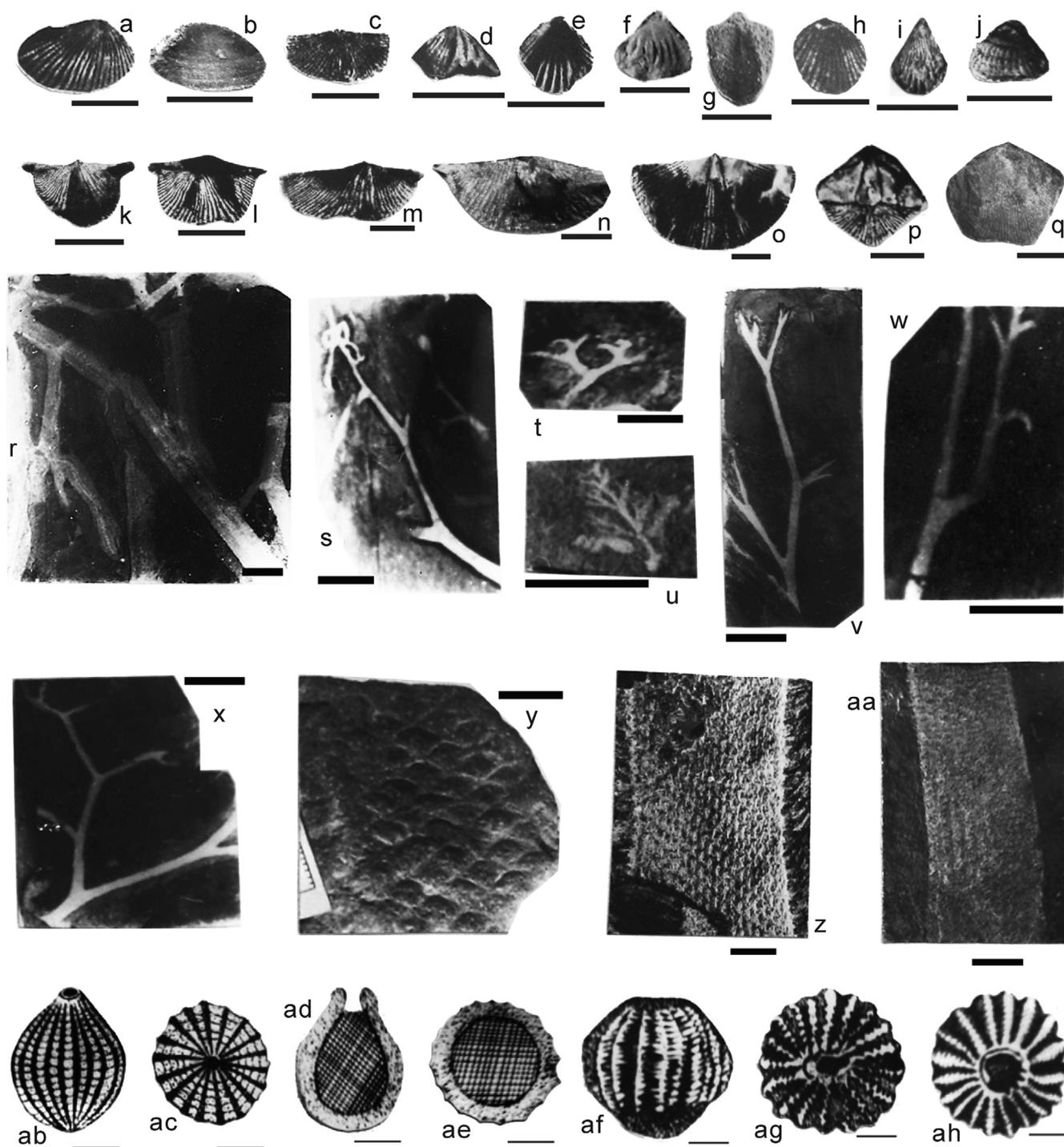
### 3.3. Rimjin System

The Rimjin System which mainly comprises terrigenous and volcanogenic sediments with a few intercalation of carbonate layers overlies the Precambrian Sangwon System or the lower Paleozoic Hwangju System (Kang, 1984; Kim and Kang, 1993; Pak, 1996; Om et al., 1996; Kim et al., 2012); its basal contact is known to be structural or unconformable in different localities. Yamaguchi (1951) reported the occurrence of *Monograptus*, a Silurian graptolite, and *Cypridea*, a Devonian non-marine ostracod from 'the uppermost formation of the so-called [Precambrian] Sangwon System near the Kumchon area; the uppermost formation represents un-metamorphosed Yeochek unit of the Yeoncheon

complex, which is often regarded as part of the Rimjin System (Cho et al., 1995; Ree et al., 1996; Kee et al., 2008). It is unfortunate that Yamaguchi (1951) did not provide illustration and systematic description for these fossils with biostratigraphic and paleobiogeographic significance.

In the 1960s, Devonian brachiopods and echinoderms were discovered from the strata which had been previously assigned to the upper Paleozoic Phyongan System. The discovery led to the establishment of the Devonian Rimjin System separated from the Phyongan System (Ham, 1981; Kang, 1984; Pak, 1987; Riu et al., 1990; Pak, 1996). The discovery of a charophyte genus *Sycidium* including *S. melo* var. *pskowensis*, *S. reticulatum* and *S. anhuaense* (Figs. 6ab–ah) confirmed the Devonian age of the Rimjin System (Kang, 1984; Pak, 1987; Riu et al., 1990; Om et al., 1996; Pak, 1996). *Sycidium* is a diagnostic Devonian charophyte in Eurasia and North America (Conkin et al., 1972; Feist and Grambast-Fessard, 1991; Mamet, 1991; Feist et al., 2000; Table 2) and *S. reticulatum* is regarded as a cosmopolitan species (Feist et al., 2000). It is of interest that the *Sycidium* species of the Rimjin System also occur in the Devonian strata of South China (e.g., Wang and Chang, 1956; Wang, 1976; Sun, 1989).

Various marine invertebrate fossils such as brachiopods, gastropods, bryozoans, crinoids, bivalves, ostracods and rugose corals, microfossils such as algae, and terrestrial plants were also documented from the Rimjin System (Choi et al., 2015, tables 1–3; Fig. 6). The brachiopods are the most abundant component of the Rimjin marine fauna (Figs. 5a–q). Pak (1996) interpreted that the age of the brachiopod assemblage ranges from the Middle Devonian to early Carboniferous. On the basis of the additional materials including brachiopods, ostracods and plants from the Rimjin System (Table 2), Kim et al. (2012) claimed that the system ranges from Givetian (Middle Devonian) to Famennian (Late Devonian). Pak (1996) considered that the brachiopod assemblage of the Rimjin System is comparable to Late Devonian *Yunnanellina-Sinospirifer* and *Yunnanella-Huanospirifer* assemblages of the Xikuangshan Formation of the Hunan area, South China (Ma et al., 2009; Ma and Zong, 2010). Kim et al. (2012) reported *Yunnanella triplicate* [= *Yunnanellina triplicata*] from the Rimjin System. *Yunnanellina* is the predominantly Famennian taxon that abundantly occurs in the Hunan and Guangxi areas of South China (Ma, 1995); *Y. triplicata* occurs in the Upper Devonian Xikuangshan Formation of the Hunan area (Wang and Bai, 1988) and Liujiang Formation of the Guangxi area (Zhang and Pojeta, 1986). This supports a close paleobiogeographic affinity of the Rimjin System to the Hunan-Guangxi area, the south-central part of the South China Block where shallow marine carbonates and clastics were deposited (Ma et al., 2009, fig. 2); the area stretches over the Yangtze and Cathaysia blocks. The second most abundant component of the Rimjin fossil assemblage is the Devonian



**Fig. 6.** Representative brachiopods, land plants and charophytes from the Rimjin System. (a)–(q) Brachiopods figured in Pak (1996), scale bar = 10 mm; (a) *Schizophoria* cf. *upensis* Sarytcheva; (b) *Schizophoria* sp.; (c) *Schucertella* cf. *matyrica* Nalivkin; (d) *Camarotoechia panderi* (Semenov et Moeller); (e) *Ptychomaletoechia shetienchiaoensis* (Tien); (f) *Pleuropugnoides* cf. *kinlingensis* (Grabau); (g) *Atrypa* cf. *richthofeni* (Kayser); (h) *Spinatrypa lungkouchungensis* (Tien); (i) *Retzia* sp.; (j) *Spinatrypa semilukiana* Ljaschenko; (k and l) *Cyrtospirifer sinensis* (Grabau); (m) *Cyrtospirifer* cf. *rudkinensis* Ljaschenko; (n) *Cyrtospirifer* sp.; (o) *Hunanospirifer* cf. *ninghsiangensis* (Tien); (p) *Tenticospirifer tenticulum* de Verneuil; (q) *Spirifer?* sp. (r)–(aa) Terrestrial plant fossils from the Rimjin System; specimens of (r) to (w) are figured in Kang (1984) and those of (x) to (aa) in Pak (1996); scale bar = 10 mm; (r) *Taeniochrada decheniana* cf. *lata* Tsch; (s) *Psilophyton* cf. *princeps* Dawson; (t) *Asteroxylon elberfeldense* Krausel et Weyland; (u) *Protopteridium hostimense* Krausel et Weyland; (v) *Pseudouralia sibirica* Petrosjan; (w) *Protopteridium minutum* Halle; (x) *Hostimella hostimensis* Potonie et Bernard; (y) *Leptophloeum suzhouense* Chang; (z) *Leptophloeum rhombicum* var. *rhombicum* Jum; (aa) *Leptophloeum rhombicum* var. *minutum* Jum. (ab)–(ah) Charophyte fossils figured in Kang (1984), scale bar = 0.5 mm; (ab)–(ae) *Sycidium reticulatum* Sandberger; (ab) Lateral view; (ac) Apical view; (ad) Longitudinal cross-section view; (ae) Transverse cross-sectional view; (af)–(ah) *Sycidium anhuaense* Wang; (af) Lateral view; (ag) Apical view; (ah) Bottom view.

terrestrial plants (Table 2; Figs. 6r–aa). Kang (1984) considered that the assemblage is the Middle to Late Devonian in age on the basis of the occurrence of *Leptophloeum*, the Middle to Late Devonian cosmopolitan lycophyte (Li et al., 1986; Wang et al., 2005). Pak and Kang (1987) claimed that the Rimjin flora is comparable with that of the Upper Devonian Wutong Formation in South China. In particular, the occurrence of *Leptophloeum rhombicum* and *Hamatophyton verticillatum* from the Rimjin System (Choi et al., 2015, table 3), which are the most dominant and widespread plants in the Late Devonian (Famennian) of South China Block (Cai, 2000; Wang et al., 2006) suggests that the Rimjin System was biogeographically closely linked to the South China Block. *H. verticillatum* is the Famennian species endemic to the Jiangsu-Anhui-Hunan area (Wang et al., 2006) where coastal-marine clastics were deposited (Ma et al., 2009, fig. 2); the area stretches over the Yangtze and Cathaysia blocks. Kim et al. (2011) reported four Devonian corals from the upper part of the Middle Ordovician Mandal Series in the Seungho area near Pyeongyang (Fig. 1). Choi et al. (2015) considered that *Calceola* sp. of these corals (Kim et al., 2011, fig. 5-1) is similar to *Calceola sandalina* from the Lower Devonian strata of the Guangxi and Yunnan areas (Zhang and Pojeta, 1986; Yu and Ruan, 1988). *C. sandalina* is a species that widely distributed in Gondwana during the late Early to Middle Devonian (Wright et al., 2010; Mergl, 2014). This suggests that the Rimjin System might have been exposed in wider area outside the Imjingang Belt.

### 3.4. Songrim Conglomerate

The Songrim Conglomerate is a fluvial deposit that constitutes the basal unit of the Songrim Series of the Jurassic Taedong System (Fig. 2). The conglomerate is exposed in small outcrops near the Songrim area where it unconformably overlies the lower Paleozoic Hwangju System (Lee et al., 2013a, fig. 1; Fig. 3c). Shimizu et al. (1934) first reported invertebrate fossils which are included as clasts in the conglomerate and not the Mesozoic in age. Tabulate corals are the most abundant components, and other fossils such as cephalopods, brachiopods and stromatoporoids occur as minor components (Shimizu et al., 1934; Yabe and Sugiyama, 1937; Hamada, 1958; Pak, 1976; Kim, 1990). Favositids and halysitids predominate the tabulate coral assemblage, and heliolitids and syringoporids occur as subordinate components (Lee et al., 2013a, table 2; Fig. 7).

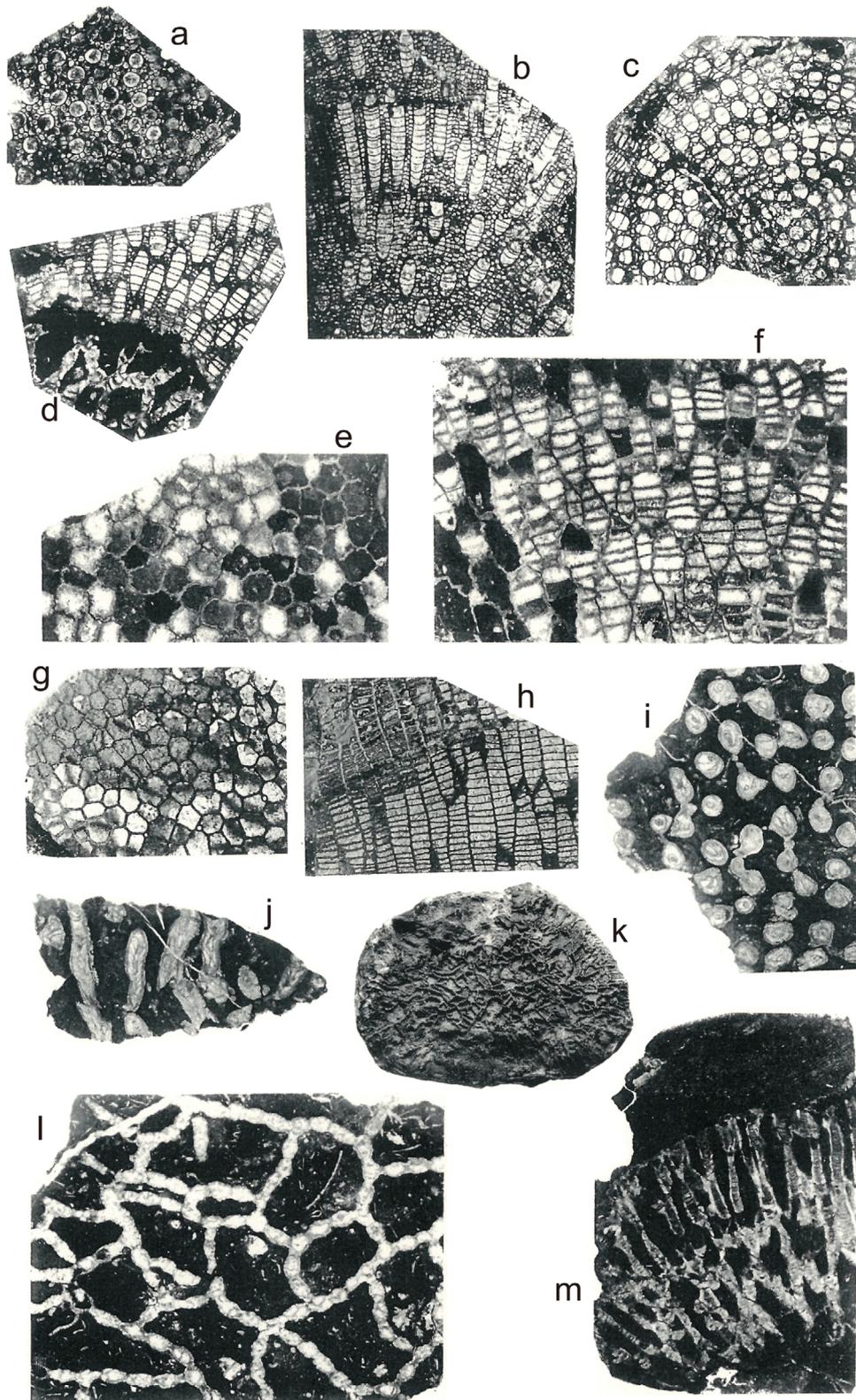
The Songrim Conglomerate is divided into the lower calcareous and upper clastic units (Pak, 1976), and it was previously suggested that the age of the tabulate corals in the lower part ranges from the Late Ordovician to late Carboniferous (Shimizu et al., 1934; Yabe and Sugiyama, 1937; Pak, 1976; Kim, 1990).

The worldwide stratigraphic occurrences of these corals (Hill, 1981) are summarized in Table 1, and their common stratigraphic ranges suggest that the age of the coral assemblage of the Songrim Conglomerate ranges from the Late Ordovician to late Silurian. Lee et al. (2013a) noticed the absence of agelolitids such as *Agelolites*, a diagnostic Late Ordovician coral taxon (Hill, 1981) in the conglomerate, and suggested that the tabulate coral assemblage of the Songrim Conglomerate is most likely to be the Silurian. However, subordinate occurrences of corals and other fossils of the Devonian or even Carboniferous age in the conglomerate (Pak, 1976; Ham, 1982; Riu et al., 1990; Kim, 1990) suggests that the clasts bearing these fossils may have been also supplied from the strata younger than the Silurian (Lee et al., 2013a).

## 4. MIDDLE PALEOZOIC STRATA IN SOUTH KOREA

In contrast to the discoveries of the Late Ordovician to Devonian fossils in North Korea, comparable paleontologic evidence has yet to be found in South Korea. It is the only exception that Lee (1980) reported Silurian conodonts in the Hoedongri Formation exposed in the Jeongseon area of the Taebaek Basin (Fig. 1). Recently, Lee et al. (2016) reported a new conodont assemblage in the formation that includes *Distomodus kentuckyensis*, the nominate species of the early Llandovery 'global standard' conodont zone (Cramer et al., 2011, fig. 3). However, the highly deformed strata in the Jeongseon area generally inhibits precise stratigraphic and sedimentologic interpretation of the strata including the Hoedongri Formation; Chough (2013) further argues that the stratigraphic scheme of the Jeongseon area established by Lee (1980) is invalid. It is of interest that the conodont assemblage of the Hoedongri Formation (Lee et al., 2016) differs from the Llandovery conodont fauna from South China (e.g., Lin, B.-Y., 1983; Wang and Aldridge, 2010; Chen et al., 2014). This contrasts the close paleobiogeographic affinity of the Silurian strata between North Korea and South China (see above). No occurrence of any other macrofossils in the Hoedongri Formation comparable to those of the Koksan and Wolyangri series suggests that the formation was not biogeographically linked with the North Korean strata.

Recent studies based on radiometric age data have suggested possible existence of Devonian strata in South Korea such as the Yeoncheon complex and Taeon Formation (Fig. 1). The Yeoncheon complex is distributed near the border between the two Koreas (Yamaguchi, 1951; Kee et al., 2008, fig. 3-2; Choi et al., 2015, fig. 1; Figs. 1 and 4) and often regarded as southward extension of the Rimjin System (Cho et al., 1995; Ree et al., 1996; Kee et al., 2008). SHRIMP (Sensitive High Resolution Ion Microprobe) U-Pb zircon age of an igneous rock intruding the metamorphic



**Fig. 7.** Tabulate corals indicative of Silurian age from the Songrim Conglomerate figured in Shimizu et al. (1934); all figures are  $\times 3$  unless otherwise noted. (a and b) *Plasmopora follis* Milne-Edwards and Haime; (a) Transverse thin section; (b) Vertical thin section. (c and d) *Propora yabei*, Shimizu, Ozaki and Obata; (c) Transverse thin section; (d) Vertical thin section. (e and f) *Favosites* cf. *gotlandicus* Lambe; (e) Transverse thin section; (f) Vertical thin section. (g and h) *Favosites kennihoensis* Shimizu, Ozaki and Obata; (g) Transverse thin section; (h) Vertical thin section. (i and j) *Syringopora bifurcata* Lonsdale which was described as *Syringopora bifurcata* d'Orbigny in Shimizu et al. (1934); (i) Transverse thin section; (j) Vertical thin section. (k–m) *Catenipora escharoides* Lamark which was described as *Halysites escharoides* Fischer-Benson in Shimizu et al. (1934); (k) upper surface of the specimen,  $\times 0.4$ ; (l) Transverse thin section; (m) Vertical thin section.

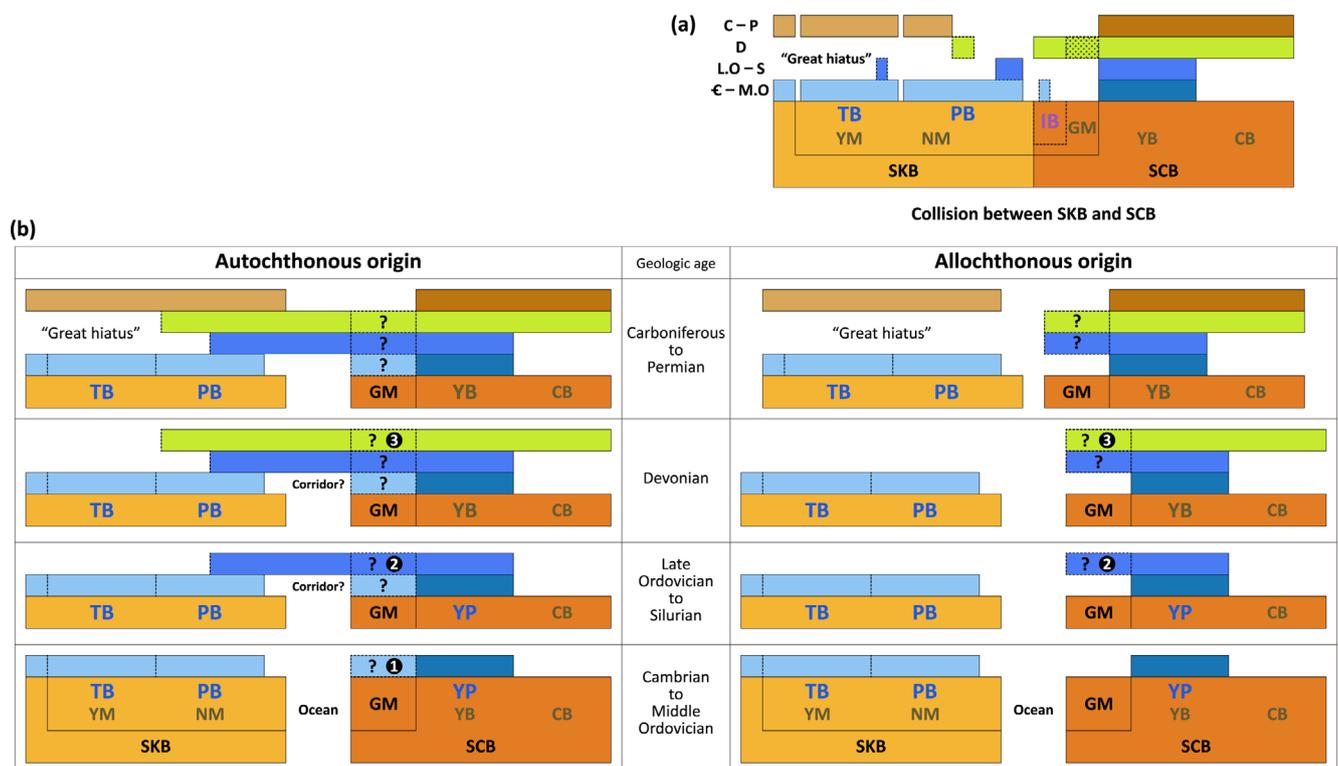
rocks of the Yeoncheon complex and detrital zircons from metasedimentary rocks indicates its possible maximum depositional age to be the Devonian (Cho et al., 2005; Kim et al., 2009; Han et al., 2017). This result confirms the Devonian age of the Rimjin System suggested by the paleontologic evidence (see above).

The Taean Formation in the western part of South Korea and on the Gyeonggi massif (Fig. 1) is another sedimentary unit often regarded as coeval to the Rimjin System. The Taean Formation has been interpreted as a “deep-water turbiditic sequence” (Lim et al., 1999; Choi et al., 2008; So et al., 2013) and considered to have experienced transitional greenschist–amphibolite metamorphism (Cho et al., 2010). SHRIMP U-Pb dating of detrital zircons of the formation indicates that the deposition may have commenced in the Devonian or later, suggesting that the formation might be part of the Imjingang Belt along with

the Rimjin System (Cho et al., 2010; Kim et al., 2014; Han et al., 2017). The latest SHRIMP U-Pb age dating studies suggest that there might be additional middle Paleozoic outcrops in the Gyeonggi massif (Kee et al., 2011; Choi S.J. et al., 2012; Na et al., 2012; Choi, 2014; Kim et al., 2014; Cho and Lee, 2016; Choi P.-Y. et al., 2016). It should be noted that the possible existence of Devonian strata in South Korea has only been suggested by detrital zircon age dating results from low-grade metamorphic rocks, and no fossils comparable to those of the Rimjin System has been discovered to date.

### 5. STATIC VS. GEODYNAMIC VIEW

The discoveries of the Late Ordovician to Devonian fossils in North Korea challenge the traditional notion of “great hiatus”



**Fig. 8.** Comparison of the autochthonous and allochthonous origin of the Late Ordovician to Devonian strata in North Korea based on the paleobiogeographic closeness between North Korea and South China during the Late Ordovician to Devonian; different colors of the sedimentary strata display paleobiogeographic differences. (a) Stratigraphic and geographic distribution of the Cambrian to Jurassic sedimentary strata in the Korean Peninsula; rectangle with dotted outline denotes the strata of which age and/or paleobiogeographic affinity is questionable (Cambro-Ordovician Hwangju System in the Imjingang Belt, possible Silurian Hoedongri Formation in Taebaeksan Basin, and possible Devonian strata in the central part of the Pyeongnam Basin); rectangle with dotted outline and filled with dots denotes the strata in the Gyeonggi massif which are determined to be middle Paleozoic (probably Devonian) in age only by zircon geochronology. (b) The interpretation of the autochthonous origin of the Late Ordovician to Devonian strata in North Korea requires to invoke a corridor in the ocean between the Sino-Korean and South China blocks. The interpretation of the allochthonous origin indicates that the strata were deposited in marine and continental basins within or peripheral to the Yangtze block of the South China Block; “?” with number denotes that geologic evidence is not known that the strata were deposited on the Gyeonggi massif. The autochthonous origin is suggestive of the absence of the “great hiatus” at least in North Korea, whereas the allochthonous origin the presence of the “great hiatus” in the Sino-Korean Block. Abbreviations: SKB = Sino-Korean Block; SCB = South China Block; TB = Taebaeksan Basin; PB = Pyeongnam Basin; YB = Yangtze block; CB = Cathaysia block; YP = Yangtze platform; YM: Yeongnam massif; NM = Nangrim massif; GM = Gyeonggi massif; IB = Imjingang Belt; The Yangtze platform (YP) is regarded as a marine sedimentary basin in the Yangtze block (YB) from the Cambrian to Silurian.

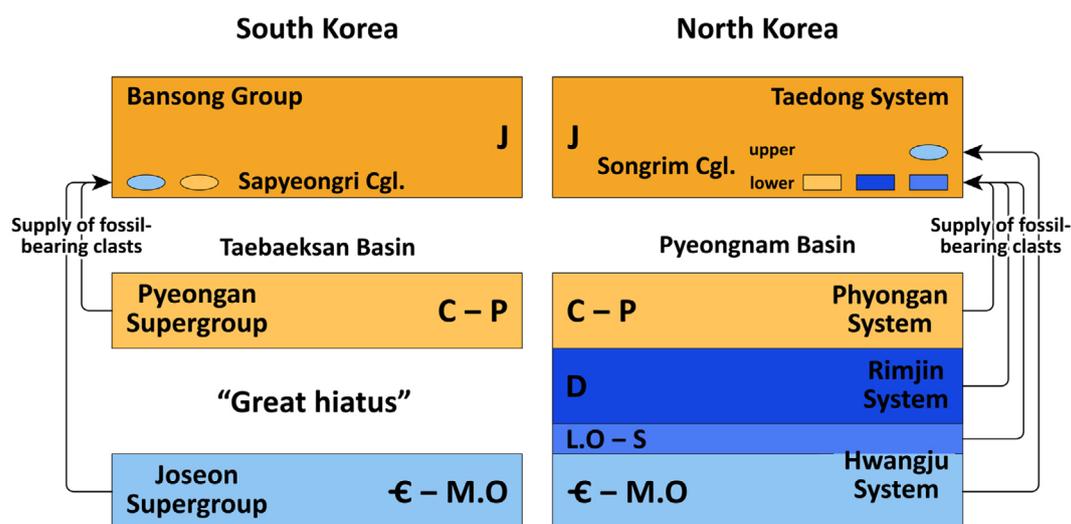
for the middle Paleozoic across the Sino-Korean Block including the Korean Peninsula. North Korean geologists claimed that the middle Paleozoic strata in North Korea are conformable with the underlying strata and thus advocating their autochthonous origin. An alternative interpretation of the presence of the middle Paleozoic strata in North Korea is plausible on the basis of recent progresses in understanding geologic history of the Korean Peninsula and adjacent regions (Fig. 8).

### 5.1. Static View

The Middle Ordovician Mandal, Upper Ordovician Sangsori, and Silurian Koksan series were interpreted as a conformable succession (Pak, 1984; Pak and Kang, 1987; Ryu and Ri, 1994; Om et al., 1996) and therefore, the Hwangju System was designated to encompass the Cambro-Ordovician and Silurian strata (Fig. 2). At the same time, it was claimed that no evidence indicative of unconformity or structural contact between the Mandal and Sangsori series has been described (Om et al., 1996). Along with the stratigraphic conformity, the faunal similarity between North Korea and South China led North Korean geologists to postulate Late Ordovician 'Miru' and Silurian 'Koksan-Songrim' seas, as a narrow extension of Yangtze Sea in South China (Pak, 1976, 1986; Pak and Kang, 1987). The 'Miru Sea' was regarded as a remnant of the Yangtze Sea during the Late Ordovician eustatic sea-level fall and 'Koksan-Songrim Sea' as part of Yangtze Sea during the ensuing Silurian sea-level rise. Likewise, Devonian 'Rimjin Sea' connected with Yangtze Sea, was envisioned for the Rimjin System (Pak and Kang, 1987; Pak, 1996). These authors thought that marine sediments were deposited in the Middle

Devonian, and later as the 'Rimjin Sea' retreated, continental sedimentation ensued in the Late Devonian. Accordingly, they interpreted a sandy conglomerate bed at the base of the Rimjin System found in the Cholwon area (Choi et al., 2015, fig. 2, locality 8) as a basal conglomerate overlying the Precambrian basement.

Recent reviews (Lee et al., 2013a, b; Choi et al., 2015) and this study ascertain the paleobiogeographic closeness between the Late Ordovician to Devonian strata of North Korea and South China. Paleogeographic reconstructions generally depict that the Sino-Korean and South China blocks were separated from each other during the Ordovician to Devonian (Torsvik and Cocks, 2016, figs. 6.4, 7.4, 8.4) by a deep ocean such as 'Shangdan Ocean' (Dong et al., 2013). Paleobiogeographic analyses of the Ordovician faunas such as trilobites, brachiopods and conodonts assert that the two blocks were discrete biogeographic areas (e.g., Whittington and Hughes, 1972; Williams, 1973; Cocks and Fortey, 1990; Jeong and Lee, 2000; Zhen and Percival, 2003; Adrain et al., 2004; Zhou and Zhen, 2008), although their latitudinal and longitudinal positions show variations. Provided that the Late Ordovician to Devonian strata in North Korea are autochthonous and the two blocks were separated as discrete biogeographic areas, the paleobiogeographic closeness between North Korea and South China should be interpreted as indicating that the marine and continental basins in the South China Block were connected to those in North Korea during these periods (Fig. 8). This interpretation is supportive of Rong et al. (2003)'s claim that North Korea may be part of the Sino-Korean Block but located near the South China Block during the Silurian based on the occurrence of a probable *Retziella* brachiopod fauna in



**Fig. 9.** Comparison of fossil contents of the clasts of the Jurassic Songrim Conglomerate in North Korea and Sapsyeongri Conglomerate in South Korea which yield the Paleozoic fossils. The clasts of the Songrim Conglomerate include the Cambrian to Carboniferous fossils, whereas those of the Sapsyeongri Conglomerate the Ordovician and Carboniferous fossils, lacking the Silurian to Devonian fossils. This can be taken as evidence for the absence of the "great hiatus" at least in North Korea.

the upper Silurian Wolyangri Series. Thus, the static interpretation contends that the “great hiatus” is absent at least in North Korea.

Comparison of fossil contents in the clasts between the Songrim Conglomerate in North Korea and correlative Sapyeongri Conglomerate in South Korea appears to manifest the difference regarding the “great hiatus” (Fig. 9). The Songrim Conglomerate is 200 to 300 m thick and divided into the lower part including numerous clasts of the middle Paleozoic fossils and the upper part with relatively fewer clasts of lower Paleozoic fossils (Pak, 1976). In comparison with the Songrim Conglomerate, the Sapyeongri Conglomerate of the Jurassic Bansong Group in the Danyang area contains limestone clasts which rarely yield Ordovician and Carboniferous conodonts and late Carboniferous fusulinids (Park and Cheong, 1975; Cheong and Park, 1979), but lack Silurian and Devonian fossils. This indicates that the Silurian to Devonian strata were apparently absent in the source area in the Jurassic, which contrasts the case of the Songrim Conglomerate (Fig. 9).

The clasts in the lower part of the Songrim Conglomerate are mostly angular, 10 to 20 cm in diameter, with the maximum of up to 50 cm. The Late Ordovician to Devonian age of the fossils (see above) suggests that the clasts are likely to have been supplied from the Koksan Series and Rimjin System (Lee et al., 2013a). However, the current exposures of these two strata as potential source rocks for the clasts are too small and located too far away to supply such large and angular clasts (Lee et al., 2013a, b). As the clasts of the Songrim Conglomerate contain corals, foraminifers and plants of Devonian or even Carboniferous age, Choi et al. (2015) suggested that the geographic extent of the Rimjin System may have been much greater than the current exposures. The occurrence of Devonian corals in the central part of the Pyeongnam Basin (Kim et al., 2011; Fig. 1) further supports this notion of previously greater extent of the Rimjin System. Based on identical detrital zircon age distributions from metasedimentary rocks of the Yeoncheon complex and Taean Formation and other units in the Gyeonggi massif and Okcheon Metamorphic Belt, Cho et al. (2017) postulated that the entire Gyeonggi massif might have been covered by these middle Paleozoic sedimentary strata.

## 5.2. Geodynamic View

The paleobiogeographic closeness of the Late Ordovician to Devonian fauna and flora between North Korea and South China invites an alternative interpretation of the presence of the middle Paleozoic strata in North Korea from a dynamic perspective of tectonic movement of the Sino-Korean and South China blocks and pertinent massifs of the Korean Peninsula. Since 1990s, numerous studies have pointed out that the Permo-Triassic

collision between the Sino-Korean and South China blocks caused the late Paleozoic to early Mesozoic Songrim orogeny in the Korean Peninsula (e.g., Cluzel et al., 1990, 1991; Cluzel, 1992a, 1992b; Chough et al., 2000). Several studies have suggested that the Imjingang Belt be an eastward extension of the Dabie-Sulu Belt between the Sino-Korean and South China blocks (Yin and Nie, 1993; Cho et al., 1995, 2007; Ree et al., 1996), although there are still disagreements in terms of tectono-stratigraphic identity of the belt (e.g., Oh et al., 2006; Kwon et al., 2009; Cho et al., 2017).

On the basis of zircon geochronology and metamorphic studies, the Imjingang Belt including the Rimjin System and Yeoncheon complex is considered to have tectonic affinity to the South China Block (Ree et al., 1996; Kim J.-N. et al., 2000; Li et al., 2003, 2008; Kim and Cho, 2008; Zhao and Zhou, 2009; Cho et al., 2010, 2017; Wu et al., 2010; Kim B.S. et al., 2012; Kim S.W. et al., 2014; Han et al., 2017), although Cho et al. (2017) recently suggested based mainly on SHRIMP U-Pb zircon ages that the Gyeonggi massif may be a composite terrane involving some component of a microcontinent. The fossil contents of the Rimjin System are supportive of the affinity to the South China Block (Fig. 8). The Rimjin System displays large variations in stratigraphy and thickness (Choi et al., 2015, fig. 2). Contrary to the traditional contention of autochthonous origin of the Rimjin System (see above), Kim et al. (2012) recently proposed that the distribution of and variations in the outcrops of the Rimjin System resulted from tectonic movement (see also Ro and Pak, 1987; Kim and Kang, 1993). They reported the occurrences of Late Devonian fossils in the lower part of the Rimjin System and Middle Devonian fossils in the upper part in the Kumchon area, respectively, and further noted that the stratigraphic overturn is also observed in other localities. They suggested a possibility that the strata of the Rimjin System were overturned by thrust and accordingly interpreted the basal conglomerate in the Cholwon area (see above) as breccia formed by a thrust movement.

Unlike the Rimjin System, no other evidence than paleobiogeography has been sought to investigate for tectonic affinity of the Sangsori, Koksan and Wolyangri series. Scattered small outcrops of these strata are located at topographic highs along the axial trace of synclines and distributed only in the southern part of the Pyeongnam Basin (Lee et al., 2013b, figs. 3–5; Figs. 3b–d); the coeval strata are not known to exist in the northern part of the basin (Ryu and Ri, 1994; Om et al., 1996). The paleobiogeographic closeness between North Korea and South China (see above) in the Late Ordovician to Silurian indicates that the Sangsori and Koksan series were likely deposited in or a basin(s) peripheral to the Yangtze platform. Lee et al. (2013a, b) postulated that the strata were thrust onto the Middle Ordovician Mandal Series during the Permo-Triassic collision. Therefore, these strata are

not regarded as autochthonous, but as allochthonous klippen. This appears to provide a plausible explanation for the small size of the outcrops and their location at topographic highs along the axial trace of synclines (Fig. 3). This interpretation of the allochthonous origin of the middle Paleozoic strata supports the presence of “great hiatus” in the Sino-Korean Block (Fig. 8). It is interesting to note that up to 16 m thick “basal mudstone” with intercalated mudstone and dolostone occurs in the base of the Sangsori Series (Ham, 1982; Lee et al., 2013b, figs. 2–5). In a similar fashion, the Koksan Series overlies the Sangsori Series with up to 5 m thick “basal siltstone” interval in the lowermost part (Ham, 1982; Lee et al., 2013b, figs. 2–4). These “basal mudstone” and “basal siltstone” layers at the base of scattered small outcrops of the Sangsori, Koksan and Wolyangri series should be investigated in the future in order to delineate the nature of stratal contact. The relationship of the Late Ordovician to Silurian strata, in particular the Sangori Series with the underlying strata warrants detailed examination in terms of structural geology and stratigraphy.

## 6. CONCLUDING REMARKS

The biostratigraphic review of the fossils from the Sangsori, Koksan, Wolyangri series, Rimjin System and Songrim Conglomerate in North Korea confirms that the fossils are of the Late Ordovician to Devonian in age, and the paleobiogeographic review points out that the fossils display affinity to those from the coeval strata of South China. The interpretation of the autochthonous origin of these strata suggests that the “great hiatus” is absent at least in North Korea, whereas that of the allochthonous origin suggests that it is present in the Sino-Korean Block. The following paleontologic evidence needs to be incorporated into a tectonic model for the Korean Peninsula and adjacent regions: 1) the Cambrian to Middle Ordovician strata in the Pyeongnam and Taebaeksan basins contain fossils which also occur in other regions of the Sino-Korean Block, suggesting that the two basins belonged to the Sino-Korean platform; 2) the Sangsori, Koksan, and Wolyangri series contain fossils with South China affinity, implying that the strata may be the remnant of klippen which were thrust onto the Middle Ordovician strata of the Pyeongnam Basin, and consequently they are tectonostratigraphically irrelevant and allochthonous to the Sino-Korean Block; 3) the Rimjin System contains fossils with strong South China affinity, indicating that the strata was deposited in a basin connected with the South China Block; 4) the clasts of the lower part of the Jurassic Songrim Conglomerate containing the Siluro-Devonian fossils are large, angular and calcareous, suggesting that the Koksan and Wolyangri series and Rimjin System as probable source areas for the clasts were exposed in much larger area than currently exposed.

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## REFERENCES

- Adrain, J.M., Edgecombe, G.D., Fortey, R.A., Hammer, Ø., Laurie, J.R., McCormick, T., Owen, A.W., Waisfeld, B.G., Webby, B.D., Westrop, S.R., and Zhou, Z.-Y., 2004, Trilobites. In: Webby, B.D., Paris, F., Droser, M.L., and Percival, I.G. (eds.), *The Great Ordovician Biodiversification Event*. Columbia University Press, p. 231–254.
- An, T. and Ma, W., 1993, Middle Ordovician–Lower Carboniferous of Sino-Korean platform and its paleogeography and structural significance. *Journal of China University of Geosciences (Earth Science)*, 18, 777–791. (in Chinese with English abstract)
- Aoti, K., 1942, Geology of Bunkei District in Tyosen with special references to the stratigraphy of the Tyosen Group. *Journal of the Geological Society of Japan*, 49, 279–281. (in Japanese)
- Cai, C.-Y., 2000, Nonmarine Devonian. In: *Nanjing Institute of Geology and Palaeontology (ed.), Stratigraphical Studies in China (1979–1999)*. University of Science and Technology of China, Hefei, p. 95–127. (in Chinese)
- Chen, Z., Fan, J., Hou, X., and Lu, L., 2014, The Llandovery (Silurian) conodont species diversity on the Upper Yangtze Platform, South China. *Estonian Journal of Earth Sciences*, 63, 201–206.
- Cheong, C.H. and Park, S.I., 1979, Fusulinids from the limestone gravels of the Jurassic Sapyeongri Formation, Danyang Coalfield, Korea. *The Journal of the Geological Society of Korea*, 15, 168–180.
- Cho, D.L. and Lee, S.-B., 2016, Geological report of the Gureopdo, Deokjeokdo, Baegado, Seongapdo sheets (1:50,000 scale). Korea Institute of Geoscience and Mineral Resources, 54 p. (in Korean with English summary)
- Cho, D.L., Kwon, S.T., Jeon, E.Y., and Armstrong, R., 2005, SHRIMP U-Pb zircon ages of metamorphic rocks from the Samgot unit, Yeoncheon complex in the Imjingang belt, Korea: implication for the Phanerozoic tectonics of East Asia. *Abstracts with Program, Geological Society of America*, 37, 388.
- Cho, M., Kwon, S.-T., Ree, J.-H., and Nakamura, E., 1995, High-pressure amphibolite of the Imjingang belt in the Yeoncheon-Cheongok area. *Journal of the Petrological Society of Korea*, 4, 1–19. (in Korean)
- Cho, M., Kim, Y., and Ahn, J., 2007, Metamorphic evolution of the Imjingang belt, Korea: implications for Permo-Triassic collisional orogeny. *International Geology Review*, 49, 30–51.
- Cho, M., Na, J., and Yi, K., 2010, SHRIMP U-Pb ages of detrital zircons

- in metasandstones of the Taean Formation, western Gyeonggi massif, Korea: tectonic implications. *Geosciences Journal*, 14, 99–109.
- Cho, M., Kim, T., Yang, S.-Y., and Yi, K., 2017, Paleoproterozoic to Triassic crustal evolution of the Gyeonggi Massif, Korea: tectonic correlation with the North China craton. In: Law, R.D., Thigpen, J.R., Mersch, A.J., and Stowell, H.H. (eds.), *Linkages and Feedbacks in Orogenic Systems*. Geological Society of America Memoir, 213, p. 165–197.
- Choi, D.K., 2014, *Geology and Tectonic Evolution of the Korean Peninsula*. Seoul National University Press, Seoul, 277 p. (in Korean with English summary)
- Choi, D.K. and Chough, S.K., 2005, The Cambrian–Ordovician stratigraphy of the Taebaeksan Basin, Korea: a review. *Geosciences Journal*, 9, 187–214.
- Choi, P.-Y., Rhee, C.W., Lim, S.-B., and So, Y., 2008, Subdivision of the Upper Paleozoic Taean Formation in the Anmyeondo–Boryeong area, west Korea: a preliminary approach to the sedimentary organization and structural features. *Geosciences Journal*, 12, 373–384.
- Choi, P.-Y., Kihm, Y.H., and Chun, H.Y., 2016, Geological report of the Yeongheungdo, Pungdo, Gyeongnyeolbiyeoldo, Gungido, Geado and Naepasudo sheets (1:50,000 scale). Korea Institute of Geoscience and Mineral Resources, 54 p. (in Korean with English summary)
- Choi, S.J., Kee, W.S., Ko, G.T., Koh, H.J., Kwon, C.W., Kim, B.C., Kim, S.W., Kim, Y.B., Khim, Y.H., Kim, H.C., Park, S.-I., Song, K.Y., Yeon, Y.K., Lee, S.S., Lee, S.R., Lee, Y.S., Lee, H.J., Cho, D.L., Choi, P.Y., Han, J.K., Hyeon, H.J., Hwang, J.H., Park, J., and Lee, T.H., 2012, Technical development of tectonic evolution and geological information construction, tectonic evolution of the western Gyeonggi Block and construction of geologic DB system, Part I. Basic Research Report of the Korea Institute of Geoscience and Mineral Resources, 426 p. (in Korean with English summary)
- Choi, Y.-M., Choh, S.-J., Lee, J.-Y., Lee, D.-C., Lee, J.-G., Kwon, Y.-K., Cao, L., and Lee, D.-J., 2015, Devonian strata in Imjingang Belt of the central Korean Peninsula: Imjin System. *Journal of the Petrological Society of Korea*, 24, 107–124. (in Korean with English abstract)
- Chough, S.K., 2013, *Geology and Sedimentology of the Korean Peninsula*. Elsevier, London, 363 p.
- Chough, S.K., Kwon, S.T., Ree, J.H., and Choi, D.K., 2000, Tectonic and sedimentary evolution of the Korean peninsula: a review and new view. *Earth-Science Review*, 52, 175–235.
- Cluzel, D., 1992a, Formation and tectonic evolution of early Mesozoic intramontane basins in the Ogcheon Belt (South Korea): a reappraisal of the Jurassic “Daebo orogeny”. *Journal of Southeast Asian Earth Sciences*, 7, 223–235.
- Cluzel, D., 1992b, Late Paleozoic to early Mesozoic geodynamic evolution of the Circum-Pacific orogenic belt in South Korea and Southwest Japan. *Earth and Planetary Science Letters*, 108, 289–305.
- Cluzel, D., Cadet, J.P., and Lapierre, H., 1990, Geodynamics of the Ogcheon belt (South Korea). *Tectonophysics*, 183, 41–56.
- Cluzel, D., Lee, B.J., and Cadet, J.P., 1991, Indosinian dextral ductile fault system and synkinematic plutonism in the southwest of the Ogcheon belt (South Korea). *Tectonophysics*, 194, 131–151.
- Cocks, L.R.M. and Fortey, R.A., 1990, Biogeography of Ordovician and Silurian faunas. In: McKerrow, W.S. and Scotese, C.F. (eds.), *Paleozoic Palaeogeography and Biogeography*. Geological Society of London, Memoirs, 12, p. 97–104.
- Conkin, J.E., Sawa, T., Coy, R.G., and Salman, A.M., 1972, The charophyte genus *Sycidium* in the Upper Devonian of Iowa. *Micropaleontology*, 18, 74–80.
- Cramer, B.D., Brett, C.E., Melchin, M.J., Männik, P., Kleffner, M.A., McLaughlin, P.I., Loydell, D.K., Munnecke, A., Jeppsson, L., Corrandini, C., Brunton, F.R., and Saltzman, M.R., 2011, Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and  $\delta^{13}\text{C}_{\text{carb}}$  chemostratigraphy. *Lethaia*, 44, 185–202.
- Dong, Y., Liu, X., Neubauer, F., Zhang, G., Tao, N., Zhang, Y., Zhang, X., and Li, W., 2013, Timing of Paleozoic amalgamation between the North China and South China Blocks: Evidence from detrital zircon U–Pb ages. *Tectonophysics*, 586, 173–191.
- Feist, M. and Grambast-Fessard, N., 1991, The genus concept in Charophyta: evidence from Palaeozoic to Recent. In: Riding, R. (ed.), *Calcareous Algae and Stromatolites*. Springer-Verlag, Berlin, p. 189–203.
- Feist, M., Feist, R., Mawson, R., and Talent, J.A., 2000, First fossil charophytes from Australia: a *Sycidiales* from the Frasnian (Late Devonian) Mytton Formation of northeastern Australia. *Records of the Western Australian Museum, Supplement*, 58, 249–253.
- Ham, B.S., 1981, Stratigraphy of the upper Ordovician and Middle Paleozoic formations of Korea. A Collection of Papers Presented at the National Seminar of Geologists, Industrial Publishing House, p. 50–69. (in Korean)
- Ham, B.S., 1982, Stratigraphy of the Upper Ordovician and Middle Paleozoic of Korea. Ph.D. Thesis, Kim Il Sung University, Pyeongyang, 74 p. (in Korean)
- Hamada, T., 1958, Gotlandio-Devonian Systems in Korea and northeastern China. *Journal of the Geological Society of Japan*, 66, 263–278.
- Han, S., de Jong, K., and Yi, K., 2017, Detrital zircon ages in Korean mid-Paleozoic meta-sandstones (Imjingang Belt and Taean Formation): constraints on tectonic and depositional setting, source regions and possible affinity with Chinese terranes. *Journal of Asian Earth Sciences*, 143, 191–217.
- Hill, D., 1981, Tabulata. In: Teichert, C. (ed.) *Treatise on Invertebrate Paleontology*. Part F: Coelenterata, Supplement 1, Rugosa and Tabulata, 2. Geological Society of America and University of Kansas, Lawrence, p. F430–F669.
- Hong, S.K., Jang, T.S., Kim, C.G., Pak, J.N., Pak, Y.H., Pak, Y.C., Ri, H.S., and Ri, S.D., 1997, Paleontological Fossils of Korea. The Korean Publications Exchange Association, Pyongyang, 112 p.
- Jeong, H. and Lee, Y.I., 2000, Late Cambrian biogeography: conodont bioprovinces from Korea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 162, 119–136.
- Kang, J.G., 1984, The fossils of Silurian to Devonian strata and their stratigraphic significance. Ph.D. Thesis, Kim Il Sung University, Pyeongyang, 159 p. (in Korean)
- Kawasaki, K., 1927, The flora of the Heina System (Part 1). *Bulletin of the Geological Survey of Chosen*, 6, 1–30.
- Kee, W.-S., Lim, S.-B., Kim, H., Kim, B.C., Hwang, S.K., Song, K.-Y., and Kihm, Y.-H., 2008, Geological Report of the Yeoncheon Sheet

- (1:50,000 scale). Korea Institute of Geoscience and Mineral Resources, 83 p. (in Korean with English summary)
- Kee, W.S., Koh, H.J., Kim, S.W., Kim, Y.B., Khim, Y.H., Kim, H.C., Park, S.-I., Song, K.Y., Lee, S.R., Lee, Y.S., Lee, H.J., Cho, D.R., Choi, B.Y., Choi, S.J., and Hwang, J.H., 2011, Tectonic evolution of the upper crustal units in the mid-western part of the Korean peninsula. Basic Research Report of the Korea Institute of Geoscience and Mineral Resources, 255 p. (In Korean with English summary)
- Kim, B.S., 2012, Characteristics of Paleozoic sedimentary from east China-Korean Peninsula and its tectonic significance. Ph.D. Thesis, Jilin University, Changchun, 123 p. (in Chinese with English abstract)
- Kim, B.S., Liu, Y.J., and Yang, W.M., 2011, The new finding of Paleozoic Devonian fossils in Pyongnam Basin, Korean Peninsula and its geological significance. *Journal of the Jilin University (Earth Science Edition)*, 41, 79–85.
- Kim, B.S., Liu, Y.J., Li, W.M., Liang, D.J., Kim, M.H., and Chae, Y.S., 2012, Correlation between Rimjingang belt and Dabie–Sulu orogenic belt. *Global Geology*, 15, 97–104.
- Kim, D.S., 1990, Biostratigraphy. Kim Il Sung University Press, Pyeongyang, 287 p. (in Korean)
- Kim, D.S. and Kang, J.G., 1993, On some problems of Rimjin System in Korea. *Jijilkwahak (Geoscience)*, 5, 23–31.
- Kim, H.C., Horie, K., Kee, W.-S., Hidaka, H., and Cho, D.-L., 2009, Middle Devonian SHRIMP U-Pb age of the hornblende granite and its implication on the depositional age of the Yeoncheon Group (abstract). *Proceedings of the Annual Joint Conference, Mineralogical Society of Korea and Petrological Society of Korea, Chuncheon, May 28–29*, p. 78. (in Korean)
- Kim, J.-N., Ree, J.-H., Kwon, S.-T., Park, Y., Choi, S.-J., and Cheong, C.-S., 2000, The Kyonggi shear zone of the central Korean peninsula: late orogenic imprint of the North and South China collision. *Journal of Geology*, 108, 469–478.
- Kim, S.W., Kwon, S., Santosh, M., Cho, D.L., and Ryu, I.-C., 2014, Detrital zircon U-Pb geochronology and tectonic implications of the Paleozoic sequences in western South Korea. *Journal of Asian Earth Sciences*, 95, 217–227.
- Kim, Y. and Cho, M., 2008, Two-stage growth of porphyroblastic biotite and garnet in the Barrovian metapelites of the Imjingang belt, central Korea. *Journal of Metamorphic Geology*, 26, 385–399.
- Kobayashi, T., 1930, The significance of the unconformity at the base of the Daido (Daedong) Formation. *Journal of Geological Society of Japan*, 26, 593–607. (in Japanese)
- Kobayashi, T., 1933, A sketch of Korean geology. *American Journal of Science*, 26, 585–606.
- Kobayashi, T., 1935, The Cambro-Ordovician formations and faunas of south Chosen, *Palaeontology*, Part 3. Cambrian faunas of south Chosen with a special study on the Cambrian trilobite genera and families. *Journal of the Faculty of Sciences, Imperial University of Tokyo*, Section II, 4, 49–344.
- Kobayashi, T., 1966a, The Cambro-Ordovician formations and faunas of South Korea, Part X, Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician formations of other areas, Section A, The Chosen Group of South Korea. *Journal of the Faculty of Science, University of Tokyo, Section II*, 16, 1–84.
- Kobayashi, T., 1966b, The Cambro-Ordovician formations and faunas of South Korea, Part X, Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician formations of other areas, Section B, The Chosen Group of North Korea and Northeast China. *Journal of the Faculty of Science, University of Tokyo, Section II*, 16, 209–311.
- Kobayashi, T., 1967, The Cambro-Ordovician formations and faunas of South Korea, Part X, Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician formations of other areas, Section C, The Cambrian of eastern Asia and other parts of the continent. *Journal of the Faculty of Science, University of Tokyo, Section II*, 16, 381–534.
- Kwon, S., Sajeev, K., Mitra, G., Park, Y., Kim, S.W., and Ryu, I.-C., 2009, Evidence for Permo-Triassic collision in Far East Asia: the Korean collisional orogeny. *Earth and Planetary Science Letters*, 279, 340–349.
- Lee, B.-J., Kim, Y.B., Lee, S.L., Kim, J.C., Kang, P.-C., Choi, H.-I., and Jin M.-S., 1999, Seoul-Namcheonjum Sheet (1:50,000 scale). Korea Institute of Geology, Mining and Materials, KR-99 (5)-1, 64 p.
- Lee, B.-S., Kim, N.S., and Seo, K.S., 2016, Early Silurian conodonts from the Hoedongri Formation (esp. upper part) of the Seongmaryeong section, Pyeongchang area: a preliminary report (abstract). *Proceedings of the Fall Joint Conference of Geosciences, the Geological Society of Korea, Pyeongchang, Oct. 26–29*, p. 126.
- Lee, D.-J., Choi, Y.-M., Lee, D.-C., Lee, J.-G., Kwon, Y.-K., Cao, L., and Choh, S.-J., 2013a, Upper Ordovician and Silurian deposits in the Pyeongnam Basin: 1. Songrim Conglomerate and its paleogeographic implication. *Journal of the Geological Society of Korea*, 49, 5–15. (in Korean with English abstract)
- Lee, D.-J., Choi, Y.-M., Lee, D.-C., Lee, J.-G., Kwon, Y.-K., Cao, L., and Choh, S.-J., 2013b, Upper Ordovician and Silurian deposits in the Pyeongnam Basin: Sangsori and Koksan series. *Journal of the Geological Society of Korea*, 49, 181–195. (in Korean with English abstract)
- Lee, H.Y., 1980, Discovery of Silurian conodont fauna from South Korea. *Journal of the Geological Society of Korea*, 16, 114–123.
- Li, X.-X., Dou, Y.-W., and Sun, Z.-H., 1986, The genus *Leptophloeum* Dawson based on a recent study of new material from the Junggar Basin, Xinjiang. *Acta Palaeontologica Sinica*, 25, 349–379. (in Chinese with English abstract)
- Li, Z.X., Li, X.-H., Kinny, P.D., Wang, J., Zhang, S., and Zhou, H., 2003, Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze Craton, South China and correlations with other continents: evidence for a mantle superplume that broke up Rodinia. *Precambrian Research*, 122, 85–109.
- Li, Z.X., Bogdanova, S.V., Collins, A.S., Davidson, A., De Waele, B., Ernst, R.E., Fitzsimons, I.C.W., Fuck, R.A., Gladkochub, D.P., Jacobs, J., Karlstrom, K.E., Lu, S., Natapov, L.M., Pease, V., Pisarevski, S.A., Trane, K., and Vernikovski, V., 2008, Assembly, configuration, and break-up history of Rodinia: a synthesis. *Precambrian Research*, 160, 179–210.
- Liang, K., Elias, R.J., Choh, S.-J., Lee, D.-C., and Lee, D.-J., 2016, Morphometrics and paleoecology of *Catenipora* (Tabulata) from the Xiazhen Formation (Upper Ordovician), Zhuzhai, South China. *Journal of Paleontology*, 90, 1027–1048.

- Lim, S.B., Choi, H.I., Kim, B.C., and Kim, J.C., 1999, Depositional systems of the sedimentary basin (I): Depositional systems and their evolution of the Proterozoic Paegryeong Group and Taean Formation. MOST/KIGAM, Daejeon, 116 p. (in Korean)
- Lin, B.Y., 1983, On the taxonomy and phylogeny of the Agatolitidae Kim. Bulletin of the Institute of Geology Chinese Academy of Geological Sciences, 15, 128–138.
- Lin, B.Y. and Wang, B.Y., 1987, Late Ordovician tabulate corals from Jiabosar District of Xinjiang and its stratigraphical significance. Acta Paleontologica Sinica, 26, 586–594.
- Lin, B.-Y., 1983, New developments in conodont biostratigraphy of the Silurian of China. Fossils and Strata, 15, 145–147.
- Ma, X., 1995, The type species of the brachiopod *Yunnanellina* from the Devonian of South China. Palaeontology, 38, 385–405.
- Ma, X. and Zong, P., 2010, Middle and Late Devonian brachiopod assemblages, sea level change and paleogeography of Hunan, China. Science China Earth Sciences, 53, 1849–1863.
- Ma, X., Liao, W., and Wang, D., 2009, The Devonian System of China, with a discussion on sea-level change in South China. In: Königshof, P. (ed.), Devonian Change: Case Studies in Palaeogeography and Palaeoecology. The Geological Society of London, Special Publications, 314, p. 241–262.
- Mamet, B., 1991, Carboniferous calcareous algae. In: Riding, R. (ed.), Calcareous Algae and Stromatolites. Springer-Verlag, Berlin, p. 370–451.
- Mergl, M., 2014, The first occurrence of the Devonian rugose coral *Calceola sandalina* (Linné, 1771) in the Barrandian area, Czech Republic. Folia, 48, 11–19.
- Meyerhoff, A.A., Kamen-Kaye, M., Chen, C., and Taner, I., 1991, China – Stratigraphy, Paleogeography, and Tectonics. Kluwer Academic Publishers, Dordrecht, 188 p.
- Murphy, M.A. and Salvador, A., 1999, International stratigraphic guide – an abridged version. Episodes, 22, 255–271.
- Na, J., Kim, Y., Cho, M., and Yi, K., 2012, SHRIMP U-Pb ages of detrital zircons from metasedimentary rocks in the Yeongheung-Seonjae-Daebu islands, northwestern Gyeonggi Massif. Journal of the Petrological Society of Korea, 21, 31–45. (in Korean with English abstract)
- Oh, C.W., 2006, A new concept on tectonic correlation between Korea, China and Japan: histories from the late Proterozoic to Cretaceous. Gondwana Research, 9, 47–61.
- Oh, C.W. and Kusky, T., 2007, The Late Permian to Triassic Hongseong–Odesan collision belt in South Korea, and its tectonic correlation with China and Japan. International Geology Review, 49, 636–657.
- Oh, C.W., Sajeev, K., Kim, S.W., and Santosh, M., 2006, Tectonic evolution of Korean Peninsula and adjacent crustal fragments in Asia: introduction. Gondwana Research, 9, 19–20.
- Om, H.Y., Kim, Y.H., and Ryang, C.C., 1996, Paleozoic Era. In: Geology of Korea. Foreign Languages Books Publishing House, Pyongyang, p. 80–164.
- Pak, M.H., 1996, Biostratigraphy of Middle Devonian to Early Carboniferous Strata in Korean Peninsula. Ph.D. Thesis, Central Commission for Mineralogical Resources, 175 p. (in Korean)
- Pak, Y.S., 1976, Lower and Middle Paleozoic Coral fossils in Pyongnam Basin. Ph.D. Thesis, Kim Il Sung University, Pyeongyang, 93 p. (in Korean)
- Pak, Y.S., 1983a, On the *Agetolites* in Upper Ordovician strata of Korea. Geology and Geography, 1, 4–6. (in Korean)
- Pak, Y.S., 1983b, On the *Agetolitella* in Upper Ordovician strata of Korea. Geology and Geography, 1, 15–16. (in Korean)
- Pak, Y.S., 1984, Some new opinions about the Pyongnam Basin. Geology and Geography, 4, 46–48. (in Korean)
- Pak, Y.S., 1985a, Some coral fossils found in Silurian strata (1)-*Palaeofavosites* and *Mesofavosites* from Silurian strata of Korea. Geology and Geography, 2, 31–34. (in Korean)
- Pak, Y.S., 1985b, Some coral fossils found in Silurian strata (2)-*Favosites* and *Sapporipora* on Silurian strata of Korea. Geology and Geography, 3, 17–19. (in Korean)
- Pak, Y.S., 1986, Miru Series (Upper Ordovician) and Koksan Series (Silurian) in Korea. Academy of Sciences Report of D.P.R of Korea, 5, 47–50. (in Korean)
- Pak, Y.S., 1987, Middle to Late Devonian Strata. In: Ro, S.W. and Pak, S.U. (eds.), Geology of Korea. Science Press, Pyongyang, p. 86–91. (in Korean)
- Pak, Y.S. and Kang, J.G., 1987, Upper Ordovician to Devonian paleogeography of Korea. Geology and Geography, 3, 44–48. (in Korean)
- Park, S.I. and Cheong, C.H., 1975, A study on the Jurassic Sapyeongri Conglomerate in the vicinity of Danyang, N. Chungcheongdo, Korea. The Journal of the Geological Society of Korea, 11, 24–37.
- Ree, J.-H., Cho, M., Kwon, S.T., and Nakamura, E., 1996, Possible eastward extension of Chinese collision belt in South Korea: the Imjingang belt. Geology, 24, 1071–1074.
- Riu, J.R., Paek, Y.S., and Ham, B.S., 1990, Geological Composition of Korea (Part 2 Paleozoic Strata). Industry Press, Pyongyang, 352 p. (in Korean)
- Ro, S.W. and Pak, S.U., 1987, Geology of Korea. Pyeongyang Science Press, Pyeongyang, 332 p. (in Korean)
- Rong, J.-Y. and Chen, X., 2003, Silurian biostratigraphy of China. In: Zhang, W.-T, Chen, P.-J., and Palmer, A.R. (eds.), Biostratigraphy of China. Science Press, Beijing, p. 173–236.
- Rong, J.-Y., Boucot, A.R., Su Y.-Z., and Strusz, D.L., 1995, Biogeographical analysis of Late Silurian brachiopod faunas, chiefly from Asia and Australia, Lethaia, 28, 39–60.
- Rong, J.-Y., Chen, X., Su, Y.-Z., Ni, Y.-N., Zhan, R.-B., Chen, T.-E., Fu, L.-P., Li, R.-Y., and Fan, J.-X., 2003, Silurian paleogeography of China. In: Landing, E. and Johnson, M.E. (eds.), Silurian Lands and Seas – Paleogeography Outside of Laurentia. New York State Museum Bulletin, 493, p. 243–298.
- Ryu, J.R. and Ri, J.N., 1994, Explanatory Text for Geological Map of Korea (1:1,000,000 scale). Ministry of Natural Resources Development, Pyongyang, 39 p.
- Shimamura, S., 1929, Geological Atlas of Chosen. Geological Survey of Governor-General, Chosen, No. 8, Kenjiho Shariin and Sainei Sheets.
- Shimizu, S., Ozaki, K., and Obata, T., 1934, Gotlandian deposits of northwest Korea. Journal of Shanghai Science Institute (Section 2), 1, 59–85.
- Shiraki, T., 1940, The Samcheok coalfield, Report of Coalfield Survey, Chosen, 14, Fuel Ore Research Center, Governor-General of Korea, 166 p.
- So, Y.S., Rhee, C.W., Choi, P.-Y., Seo, J.Y., and Lee E.-J., 2013, Distal tur-

- bidite fan/lobe succession of the Late Paleozoic Taean Formation, western Korea. *Geosciences Journal*, 17, 9–25.
- Sokolov, B.S., 1950, *Sistematika i istoriya razvitiya paleozojskikh korallov Anthozoa Tabulata* (Systematics and historical development of the Palaeozoic corals Anthozoa Tabulata). *Voprosy Paleontologii*, 1, 134–210. (in Russian)
- Sun, N., 2011, Ordovician Coral and Coral-like fossils (*Agetolitids* and *Amsassia*) from China. Unpublished Ph.D. Thesis, Andong National University, Andong, 141 p.
- Sun, N., Elias, R.J., Choh, S.-J., Lee, D.-C., Wang, X.-L., and Lee, D.-J., 2016, Morphometrics and palaeoecology of the coral *Agetolites* from the Xiazhen Formation (Upper Ordovician), Zhuzhai, South China. *Alcheringa*, 40, 251–274.
- Sun, Y., 1989, The *Sycidium* bed from Upper Devonian of Sichuan and its geologic significance. *Journal of Chengdu College of Geology*, 16, 28–31. (in Chinese with English abstract)
- Tateiwa, I., 1926, Geological Atlas of Chosen, Shinhung, Gotosu, Wonyongjang, Hamhung, Onori, Sohojin sheets (1/50,000). Geological Survey of Chosen. (in Japanese)
- Torsvik, T.H. and Cocks, L.R.M., 2016, *Earth History and Palaeogeography*. Cambridge University Press, Cambridge, 317 p.
- Wang, C.-Y. and Aldridge, R.J., 2010, Silurian conodonts from the Yangtze Platform, South China. *Special Papers in Palaeontology*, 83, 136 p.
- Wang, D.-M., Hao, S.-G., Tian, L., and Xue, J.-Z., 2006, Further study of the Late Devonian sphenopsis *Hamatophyton verticillatum* from China. *International Journal of Plant Science*, 167, 885–896.
- Wang, K. and Bai, S., 1988, Faunal changes and events near the Frasnian-Famennian boundary of South China. *The Canadian Society of Petroleum Geologists Memoirs*, 14, 71–78.
- Wang, Q., Geng, B.-Y., and Dilcher, D.L., 2005, New perspective on the architecture of the Late Devonian arborescent lycopsid *Leptophloeum rhombicum* (Leptophloeaceae). *American Journal of Botany*, 92, 83–91.
- Wang, S. and Chang, S.-J., 1956, On the occurrence of *Sycidium melo* var. *pskowensis* Karpinsky from the Devonian of northern Szechuan. *Acta Palaeontologica Sinica*, 4, 381–386. (in Chinese with English summary)
- Wang, Z., 1976, Middle Devonian *Sycidium* and *Chovanella* from Southwest China. *Acta Palaeontologica Sinica*, 15, 175–186. (in Chinese with English abstract)
- Whittington, H.B. and Hughes, C.P., 1972, Ordovician geography and faunal provinces deduced from trilobite distribution. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 263, 235–278.
- Williams, A., 1973, Distribution of brachiopod assemblages in relation to Ordovician palaeogeography. *Special Papers in Palaeontology*, 12, 241–269.
- Willis, B., Blackwelder, E., and Sargent, R.H., 1907, Part I. Descriptive topography and geology. In: Willis, B. (ed.), *Research in China*, Vol. 1. Carnegie Institution of Washington Monograph Series, Washington D.C., p. 1–353.
- Wright, A.J., Coen-Aubert, M., Bultynck, P., and van Vierssen, A.P., 2010, New data on occurrences of the Devonian rugose coral *Calceola* in Belgium. *Memoirs of the Association of Australasian Palaeontologists*, 39, 121–129.
- Wu, L., Jia, D., Li, H., Deng, F., and Li, Y., 2010, Provenance of detrital zircons from the late Neoproterozoic to Ordovician sandstones of South China: implications for its continental affinity. *Geological Magazine*, 147, 974–980.
- Yabe, H. and Sugiyama, T., 1937, Gotlandian *Clathrodictyon* from Tyosen (Korea). *Transactions of the Palaeontological Society of Japan*, 9, 154–157.
- Yamaguchi, T., 1951, On the so-called Yeoncheon System and its regional metamorphism. *Journal of the Geological Society of Japan*, 57, 419–438. (in Japanese with English abstract)
- Yang, Z., 1989, Enlightenment from discovering of strata of Upper Ordovician to Silurian and Devonian, Korea. *Bulletin of Nanjing Institute of Geology and Mineral Resources*, 10, 17–26. (in Chinese with English abstract)
- Yin, A. and Nie, S., 1993, An indentation model for the north and south China collision and development of the Tan-Lu and Honam fault systems, Eastern Asia. *Tectonics*, 12, 810–813.
- Yosimura, I., 1940, Geology of the Neietsu District, Kogendo, Tyosen. *Journal of the Geological Society of Japan*, 40, 112–122. (in Japanese)
- Yu, C.-M. and Ruan, Y.-P., 1988, Proposal and comment on the definition of Emsian. *The Canadian Society of Petroleum Geologists Memoir*, 14, 179–191.
- Zhai, M., Guo, J., Li, Z., Chen, D., Peng, P., Li, T., Hou, Q., and Fan, Q., 2007, Linking the Sulu UHP belt to the Korean Peninsula: Evidence from eclogite, Precambrian basement, and Paleozoic sedimentary basins. *Gondwana Research*, 12, 388–403.
- Zhang, R. and Pojeta, J. Jr., 1986, Devonian sections in Guangxi from which pelecypods were collected. *U.S. Geological Survey Professional Paper*, 1394, p. 33–43.
- Zhao, J.H. and Zhou, M.F., 2009, Neoproterozoic adakitic plutons and arc magmatism along the western margin of the Yangtze Block, South China. *Journal of Geology*, 115, 675–689.
- Zhen, Y.-Y. and Percival, I.G., 2003, Ordovician conodont biogeography-reconsidered. *Lethaia*, 36, 357–370.
- Zheng, Y.-F., Xiao, W.-J., and Zhao, G., 2013, Introduction to tectonics of China. *Gondwana Research*, 23, 1189–1206.
- Zhou, Z.-Y. and Zhen, Y.-Y., 2008, Trilobite-constrained Ordovician biogeography of China with reference to faunal connections with Australia. *Proceedings of the Linnean Society of New South Wales*, 129, 183–195.