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The Hwajeol Formation of the Taebaek Group, Korea extends from the Jiangshanian Stage to Cambrian Stage 10. The lower part of the formation incorporates the *Asioptychaspis* Zone, which is closely correlated to the *Asioptychaspis–Tsinania* Zone of North China. This study documents silicified trilobites from the lower part of the Hwajeol Formation in the Sagundari section. *Asioptychaspis subglobosa* occurs throughout the interval; hence the biozone is renamed as the *Asioptychaspis subglobosa* Zone in this study. The *Asioptychaspis subglobosa* Zone of the Hwajeol Formation yields 14 polymerid species belonging to 14 genera. Of these, 11 species including three new species are documented for the first time in Korea. Among other taxa, the occurrence of *Caznaia* is stratigraphically significant because two biozones were established in Australia based on representatives of this genus: i.e., the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones in ascending order. Owing to the lack of cosmopolitan trilobites, the international correlation of these Iverian biozones has been equivocal. The occurrence of *Caznaia* from the *Asioptychaspis subglobosa* Zone of Korea indicates that the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones of Australia are correlated with the *Asioptychaspis subglobosa* Zone of Korea and the *Asioptychaspis–Tsinania* Zone of North China.

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Key words: Biostratigraphy, *Caznaia*, correlation, North China, Korea, Australia.

THE LOWER Palaeozoic Taebaek Group of the Taebaeksan Basin, Korea, is a mixed siliciclastic–carbonate succession deposited in a shallow marine environment, which occupied the eastern part of the Sino-Korean Block. The first trilobite biostratigraphic scheme for the Taebaek Group, established by Kobayashi (1935, 1966), was accepted for decades without significant modification, although many of the biozones were erected on the basis of a few poorly preserved specimens. However, the discovery of weathered out (exhumed) silicified trilobites from the Taebaek Group has led to the revision of some trilobite biozones (Choi *et al*., 2003, Kang & Choi 2007, Sohn & Choi 2007, Lee & Choi 2007). Moreover, recent studies using acid-extracted silicified trilobites have begun to revise the biostratigraphy of the Taebaek Group (Park & Choi 2011b, Park *et al*., 2012, 2013).

The Hwajeol Formation of the Taebaek Group spans the Jiangshanian Stage to Cambrian Stage 10, and recent research has revealed that the formation contains three biozones, the *Asioptychaspis* Zone, *Quadraticephalus* Zone, and the saukiid-dominated fauna, in ascending order (Sohn & Choi 2005, 2007). However, this research was based on relatively few weathered out specimens, many of which show only the ventral side of the sclerites. Consequently, the full composition of the biozones has remained unclear, and the cranidia and pygidia of some species were mismatched.

This study reports an acid-extracted silicified trilobite fauna from the lower part of the Hwajeol Formation in the Sagundari section. The studied interval, which was assigned to the *Asioptychaspis* Zone by Sohn & Choi (2007), invariably yields *Asioptychaspis subglobosa* (Sun 1924), and hence it is renamed the *Asioptychaspis subglobosa* Zone herein. Interestingly, *Caznaia*, which, to date, was documented only from Australia, has been discovered from the *Asioptychaspis subglobosa* Zone. Two biozones were established on the basis of this genus in Australia: i.e., the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones (Shergold 1975, 1995). The occurrence of *Caznaia* in the *Asioptychaspis subglobosa* Zone of the Hwajeol Formation, Korea, will be useful for the international correlation of the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones of Australia.

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Geological setting, fossil locality and material

The Joseon Supergroup represents the Cambro-Ordovician sedimentary rocks in Korea and was divided into the Taebaek, Yeongwol, Yongtan, Pyeongchang and Mungyeong groups by Choi (1998). Of these, the Taebaek Group, which represents a shallow marine continental shelf environment (Choi *et al*., 2004) comprises, in ascending order, the Jangsan/Myeonsan, Myobong, Daegi, Sesong, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan and Duwibong formations (Choi *et al*., 2004).

Kobayashi (1935) originally proposed the concept of the Hwajeol Formation, in which the boundary between the underlying Sesong Formation and the Hwajeol Formation was defined by biostratigraphy. Five biozones, the *Prochuangia*, *Chuangia*, *Kaolishania*, *Dictyites* and *Eoorthis* zones, in ascending order, were originally established within the Hwajeol Formation (Kobayashi 1935). Sohn & Choi (2005) redefined the boundary of the Hwajeol Formation on lithological criteria, by which the base of the Hwajeol Formation became younger than that in the concept of Kobayashi (1935). Accordingly, only the upper two biozones, the *Dictyites* and *Eoorthis* zones, were placed within the Hwajeol Formation. These two biozones were established on only a few fragmentary trilobites and brachiopods, and Sohn & Choi (2005, 2007) revised the biostratigraphy of the Hwajeol Formation using trilobites.

The Hwajeol Formation consists of calcareous shale, nodule-bearing shale, limestone-shale couplets, flaser wackestone to packstone, or grainstone, sparsely intercalated with limestone pebble conglomerate. Kwon *et al*. (2006) regarded the Hwajeol Formation as having been deposited in inner to outer marine ramp environments.

All the material for this study was collected from a 3 m interval of the lower Hwajeol Formation exposed at the Sagundari section (129°01′03.4″E, 37°04′57.0″N; Fig. 1; see Park & Choi, 2011a for locality map). Sohn & Choi (2007) established the *Asioptychaspis* Zone using the material collected from this locality. However, this study proposes renaming the biozone as the *Asioptychaspis subglobosa* Zone. Sohn & Choi (2007) reported the occurrences of *Pseudagnostus planulatus* (Raymond, 1924), *Asioptychaspis subglobosa* (Sun, 1924), *Tsinania canens* (Walcott, 1905) and *Haniwa sosanensis* Kobayashi, 1933 from the *Asioptychaspis* Zone at the Sagundari section, and correlated this biozone to the ‘*Ptychaspis*’–*Tsinania* Zone of North China. Because only *Asioptychaspis* morphology has been discovered in North China (see Chough *et al*., 2010, Kim 2012), the biozone name ‘*Ptychaspis*’–*Tsinania* Zone should be changed to the *Asioptychaspis*–*Tsinania* Zone. Park & Choi (2009, 2010, 2011a) documented the ontogeny of *Tsinania canens* (Walcott, 1905), *Asioptychaspis subglobosa* (Sun, 1924) and *Haniwa quadrata* Kobayashi, 1933, respectively, based on the material recovered from this part of the Hwajeol Formation.

Blocks of the silicified fossil-containing limestone-shale couplets and limestone pebble conglomerates were collected from nine beds, which were marked from bottom to top as CHBd01 to CHBd10 (Fig. 1) excluding CHBd09, which was unfossiliferous. Limestone blocks were dissolved with hydrochloric acid. More than 200 protaspides, 1000 cranidia, 359 free cheeks, 172 thoracic segments and more than 800 post-protaspid pygidia including immature specimens were obtained for this study. Silicified specimens of stratigraphically long-ranging agnostoids have also been collected, but they will be described elsewhere. The CHBd03 and 08 horizons were most productive, whereas CHBd01 and CHBd02 together produced fewer than 147 specimens including fragments. This bias in fossil productivity probably contributes to the high diversity of trilobites in CHBd08, and the low diversity in CHBd01 and CHBd02 (Fig. 1).

Implications for correlation with North China and Australia

Among the 14 species of 14 genera documented from the *Asioptychaspis subglobosa* Zone of the Hwajeol Formation, seven species occur in common with the *Asioptychaspis*–*Tsinania* Zone of North China: *Asioptychaspis subglobosa*, *Haniwa quadrata*, *Tsinania canens*, *Caznaia coreaensis*, ?*Saukia aojii*, *Wuhuia belus* and *Pseudokoldinioidia* sp. cf. *P. granulosa*. In addition, three genera overlap in occurrence; two of them are based on the new species (*Koldinioidia choii* and *Akoldinioidia latus*) and the other one is *Parakoldinioidia* sp. 1. The four species of four genera that uniquely occur in the Hwajeol Formation (*Gumunsoia* sp. 2, *Guangxiaspis* sp. 1, ?*Mansuyia* sp. 1 and *Baikadamaspis* sp. 2) have been documented on the basis of only a few specimens (a single cranidium or no more than three cranidia). These results indicate a strong stratigraphic correlation between the *Asioptychaspis subglobosa* Zone of Korea and the *Asioptychaspis*–*Tsinania* Zone of North China (Fig. 2).

The Cambrian of North China and Korea are generally dominated by species endemic to the Sino-Korean Craton, which can be highly useful for detailed correlations between these regions (e.g., Park *et al*., 2013). Renaming the lowermost biozone of the Hwajeol Formation as the *Asioptychaspis subglobosa* Zone has the merit of more accurate correlation with North China in this regard. The detailed stratigraphic occurrence of each trilobite taxon within and around the *Asioptychaspis*–*Tsinania* Zone of North China has yet to be documented. Because there are several species of *Asioptychaspis* documented in North China, such as *A. ceto* (Walcott, 1905), *A. cacus* (Walcott, 1905), *A. calyce* (Walcott, 1905), *A. subglobosa* (Sun,

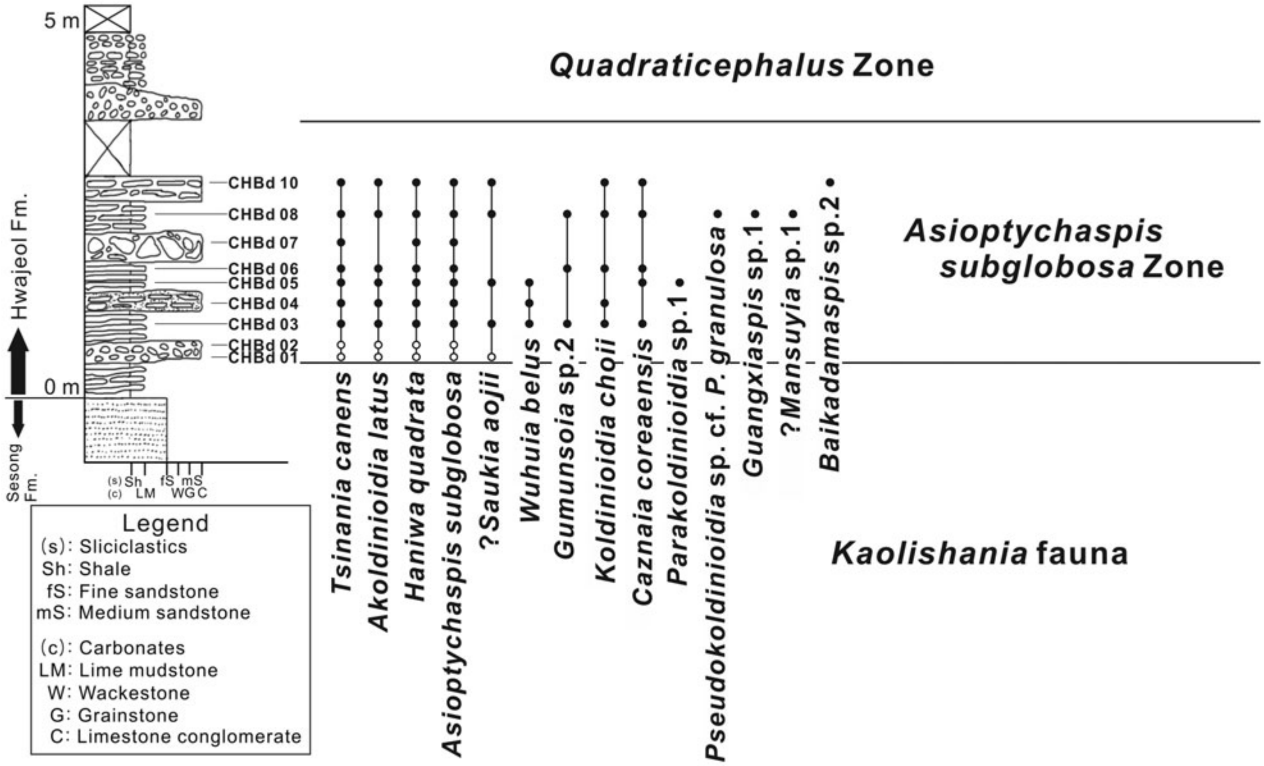

Fig. 1. Lithologic column of the lower part of the Hwajeol Formation with stratigraphic occurrences of trilobites of the *Asioptychaspis subglobosa* Zone. The open circles of CHBd01 and CHBd02 indicate the relatively rare occurrence of specimens (see text).

STAGE	TAEBAEK	NORTH CHINA		AUSTRALIA			LAURENTIA	
	TRILOBITE	TRILOBITE	CONODONT	TRILOBITE	CONODONT		TRILOBITE	CONODONT
JIANGSHANIAN	*Quadraticephalus*	*Quadraticephalus*	*Proconodontus muelleri*	*Neoagnostus quasibilobus-Shergoldia nomas*	*Eoconodontus*	*Hispidodontus resimus*	*Saukiella junia*	*Eoconodontus notchpeakensis*
				Sinosaukia impages	*Proconodontus muelleri*			*Proconodontus muelleri*
				Rhaptagnostus clarki maximus-Rhaptagnostus papilio		*Teridontus nakamurai*		
			Proconodontus posterocostatus	*Rhaptagnostus bifax-Neoagnostus denticulatus*	*Proconodontus posterocostatus*		*Saukiella pyrene-Rasettia magna*	*Proconodontus posterocostatus*
	Asioptychaspis subglobosa	*Asioptychaspis-Tsinania*		*Rhaptagnostus clarki prolatus-Caznaia sectatrix*				
			Proconodontus tenuiserratus	*Rhaptagnostus clarki patulus-Caznaia squamosa-Hapsidocare lilyensis*				*Proconodontus tenuiserratus*
	Kaolishania fauna	*Kaolishania pustulosa*	*Westergaardodina aff.fossa - Prooneotodus rotundatus*	*Peichiashania tertia-Peichiashania quarta*				

Fig. 2. Biostratigraphical correlation of Jiangshanian Stage transitional interval of the Taebaek Group, Korea, with those of North China, Australia and Laurentia. Modified after An *et al*. (1983), Wang (1985), Zhang & Jell (1987), Miller (1988), Shergold (1995) and Shergold & Geyer (2003).

1924), *A. shansiensis* (Sun 1935) and *A. asiatica* (Resser & Endo, 1937), detailed biostratigraphic research is likely to reveal stratigraphic differences in the occurrence of each species of *Asioptychaspis*. In contrast, no other species of *Asioptychaspis* occur in the *Asioptychaspis subglobosa* Zone, and below the base of the Hwajeol Formation is an unfossiliferous sandstone-dominant interval of the Sesong Formation (Fig. 1, see also Park *et al*., 2012), so that the full expression of the faunal change between the *Asioptychaspis subglobosa* Zone and the underlying *Kaolishania* fauna (see Park *et al*., 2012) is concealed by the currently unfossiliferous (or unstudied) interval. Therefore, the base of the *Asioptychaspis subglobosa* Zone of Korea and that of the *Asioptychaspis–Tsinania* Zone of North China might be stratigraphically diachronous. When the stratigraphic differences in the occurrence of each species of *Asioptychaspis* within the *Asioptychaspis–Tsinania* Zone of North China are revealed, the stratigraphic range of *A. subglobosa*, among others, may be correlated with the *Asioptychaspis subglobosa* Zone of Korea.

Caznaia has thus far been reported only from Australia. The two species, *C. squamosa* and *C. sectatrix*, are the eponymous trilobite species of two biozones: the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones, which are included within the Iverian Stage of Australia. However, the correlation of these biozones to the biostratigraphy of North China and other regions has been equivocal because this interval in Australia lacks the trilobites useful for international correlation (see Shergold 1975). Consequently, Zhang & Jell (1987), Shergold (1995, 1997), Shergold & Geyer (2003) and Sohn & Choi (2007) correlated them to the upper part of the *Kaolishania* Zone or *Kaolishania pustulosa* Zone of North China, whereas Zhang (2003) correlated them to the '*Tsinania–Ptychaspis*' Zone (now the *Asioptychaspis–Tsinania* Zone). In fact, correlating the two Iverian biozones to the upper part of the *Kaolishania* Zone is incompatible with the conodont biostratigraphy. Nicoll & Shergold (1991) and Shergold (1995) placed the base of the *Proconodontus posterocostatus* and *Tridontus nakamurai* zones from Queensland in the middle of the *Rhaptagnostus clarki prolatus–Caznaia sectatrix* Zone. However, the *Proconodontus posterocostatus* Zone is considered to correlate with the upper part of the *Asioptychaspis–Tsinania* Zone of North China (see Shergold & Geyer 2003), which is very similar to the *Asioptychaspis subglobosa* Zone of Korea. Therefore, a discrepancy appears between the conodont biostratigraphy and the trilobite biostratigraphy, if the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones of Australia are correlated to the *Kaolishania* Zone. The occurrence of *Caznaia* from the *Asioptychaspis subglobosa* Zone of Korea provides crucial information for the correlation of the two biozones of Australia. Based on the occurrence of *Caznaia*, the *Rhaptagnostus clarki patulus–Caznaia squamosa–Hapsidocare lilyensis* and *Rhaptagnostus clarki prolatus–Caznaia sectatrix* zones of Australia are correlated to the *Asioptychaspis subglobosa* Zone of Korea and, in turn, to the *Asioptychaspis–Tsinania* Zone of North China (Fig. 2). The two Iverian biozones of Australia are younger than the *Kaolishania* Zone of North China, as Zhang (2003) suggested. This correlation is also compatible with the above-mentioned conodont data, solving the problem of stratigraphic discrepancy between trilobite biostratigraphy and conodont biostratigraphy.

Systematic palaeontology

The morphological terms in this study follow those of Whittington & Kelly (1997), but the glabella used herein excludes the occipital ring. Length refers to sagittal distance, whereas width means transverse distance. All of the specimens are housed in the palaeontological collections of the Korea Polar Research Institute, with registered numbers prefixed KOPRIF.

Family MISSISQUIDAE Hupé, 1955

Pseudokoldinioidia Endo, 1944

Type species. *Pseudokoldinioidia granulosa* Endo, 1944 from the *Tsinania canens* Zone of Liaoning Province, North China.

Pseudokoldinioidia sp. cf. **P. granulosa** Endo, 1944 (Fig. 3A–E)

cf. 1944 *Pseudokoldinioidia granulosa* Endo, p. 72, pl. 9, fig. 6.

Material. A single fragmentary cranidium.

Occurrence. CHBd08 of the Hwajeol Formation in the Sagundari section.

Remarks. The holotype of *P. granulosa* is a poorly preserved cranidium. Nevertheless, the cranidium from the Hwajeol Formation is morphologically similar to *P. granulosa* in having long, posteriorly curved posterolateral projections of the fixed cheeks. In addition, *P. granulosa* was discovered from the *Asioptychaspis–Tsinania* Zone of North China, which is well correlated with the *Asioptychaspis subglobosa* Zone of Korea. There are two other species of *Pseudokoldinioidia* documented from the *Asioptychaspis–Tsinania* Zone of North China, *P. taiziheensis* Duan & An in Duan *et al*., 1986 and *P. hemicycla* Duan *et al*., 2005. However, these species differ from the cranidium from the Hwajeol Formation in having slightly anteriorly directed, or horizontally directed posterolateral projections of the fixed cheeks.

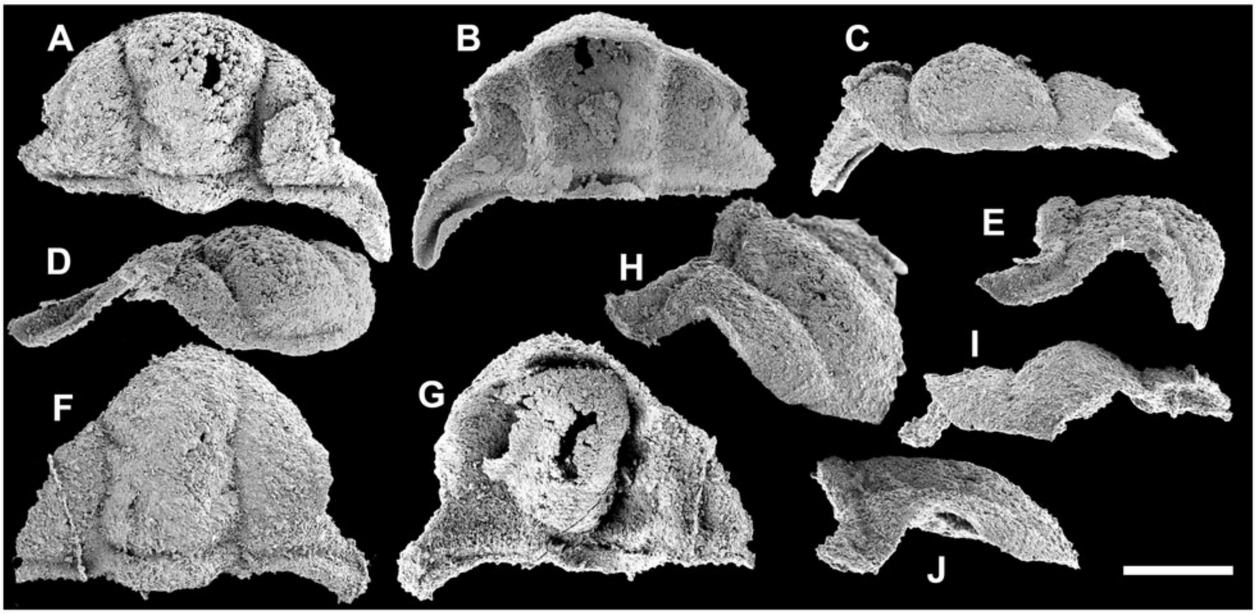

Fig. 3. Pseudokoldinioidia sp. cf. *P. granulosa* (Endo, 1944) and *Parakoldinioidia* sp. 1 from Hwajeol Formation, Sagundari section, Korea. **A–E**, *Pseudokoldinioidia* sp. cf. *P. granulosa*; **A–E**, Dorsal, ventral, anterior, anterior-lateral and lateral views of cranidium, KOPRIF 1079. **F–J**, *Parakoldinioidia* sp. 1; **F–J**, Dorsal, ventral, oblique lateral, anterior and lateral views of cranidium, KOPRIF 1080. A fragmentary cranidium of *Koldinioidia choii* is attached to the ventral side. Scale bar = 1 mm.

Parakoldinioidia Endo in Endo & Resser, 1937

Type species. Parakoldinioidia typicalis Endo in Endo & Resser, 1937 from Liaoning Province, North China.

Parakoldinioidia sp. 1 (Fig. 3F–J)

Material. A single fragmentary cranidium.

Occurrence. CHBd05 of the Hwajeol Formation in the Sagundari section.

Remarks. An incomplete cranidium is 2.3 mm long, which is likely to represent a morphologically immature individual. However, it has a triangular outline, with the glabella constricted in the mid-length, which are characteristics of *Parakoldinioidia*. This cranidium might belong to *P. typicalis* Endo in Endo & Resser, 1937, because *P. typicalis* is the only *Parakoldinioidia* species documented from the *Asioptychaspis–Tsinania* Zone of North China (see Lee *et al*., 2008), which is stratigraphically equivalent to the *Asioptychaspis subglobosa* Zone of Korea.

Family TSINANIIDAE Kobayashi, 1935

Remarks. Tsinaniidae is considered to belong to the Suborder Illaenina Jaanusson, 1959 (Fortey 1997, Adrain 2011). Park *et al*. (2014) demonstrated that Tsinaniidae arose from the Kaolishaniidae Kobayashi, 1955, which belongs to the Suborder Leiostegiina Bradley, 1925 (Fortey 1997, Adrain 2011). Park *et al*. (2014) noted gradual morphological transitions from species of *Mansuyia* to *Tsinania*. However, Zhu *et al*. (2013) argued that *Lonchopygella* forms the most plesiomorphic branch of Tsinaniidae, emphasizing that the trunk segmentation condition of *Lonchopygella* is intermediate between those of *Mansuyia* and other tsinaniids.

Tsinania Walcott, 1914

Type species. Illaenurus canens Walcott, 1905 from the Chaumitien (Chaomidian) Formation, Shandong Province, North China.

Tsinania canens (Walcott, 1905) (Fig. 4)

1905 *Illaenurus canens* Walcott, p. 96.
1905 *Illaenurus ceres* Walcott, p. 97.
1913 *Illaenurus canens* Walcott; Walcott, p. 222, pl. 23, figs 3, 3a–c.
1913 *Illaenurus* sp; Walcott, p. 222, pl. 23, fig. 6.
1913 *Illaenurus ceres* Walcott; Walcott, p. 223, pl. 23, figs 4, 4a.
1913 *Illaenurus dictys* Walcott, p. 224, pl. 23, figs 5, 5a.
1913 Gen. and sp. indeterminate; Walcott, p. 224, pl. 23, fig. 8.
1924 *Illaenurus pagoda* Walcott, p. 82, pl. 5, figs 4, 4a.
1931 *Tsinania canens* (Walcott); Kobayashi, p. 186, pl. 20, figs 7–9.
1931 *Tsinania canens pagoda* (Sun); Kobayashi, p. 186, pl. 20, fig. 10.
1933 *Tsinania ceres* (Walcott); Kobayashi, p. 136, pl. 14, figs 1–3.

Fig. 4. Tsinania canens (Walcott, 1905) from Hwajeol Formation, Sagundari section, Korea. **A**, Dorsal view of cranidium, KOPRIF 1081. **B**, Dorsal view of cranidium, KOPRIF 1082. **C**, Dorsal view of cranidium, KOPRIF 1083. **D**, Ventral view of cranidium, KOPRIF 1084. **E**–**G**, Dorsal, lateral and anterior views of cranidium, KOPRIF 1085. **H**–**J**, Anterior, oblique lateral and dorsal views of free cheek, KOPRIF 1086. **K**–**L**, Dorsal and anterior views of free cheek, KOPRIF 1087. **M**, Dorsal view of free cheek, KOPRIF 1088. **N**, Dorsal view of free cheek, KOPRIF 1089. **O**, Dorsal view of free cheek, SNUP 4798. **P–R**, Anterior, dorsal and lateral views of thoracic segment, KOPRIF 1090. **S–U**, Dorsal, ventral and lateral views of pygidium, KOPRIF 1091. **V**, Dorsal view of pygidium, KOPRIF 1092. **W**, Dorsal view of pygidium, KOPRIF 1093. **X**–**Z**, Dorsal, ventral and lateral views of pygidium, KOPRIF 1094. Scale bar = 1 mm for **A–C** and **H–Z**, and 1.4 mm for **D–G**.

1933 *Tsinania canens* (Walcott); Kobayashi, p. 136, pl. 14, figs 4–6.

1935 *Tsinania canens shansiensis* Sun, p. 53, pl. 5, figs 20, 21.

1935 *Tsinania canens* (Walcott); Kobayashi, p. 306, pl. 5, fig. 20; pl. 6, figs 13, 14.

1937 *Tsinania vulgaris* Resser & Endo, p. 296, pl. 56, figs 13–18.

1937 *Tsinania convexa* Resser & Endo, p. 296, pl. 56, figs 19, 20.

1937 *Tsinania longicephala* Resser & Endo, p. 296, pl. 55, figs 22–27.

1944 *Tsinania canens* (Walcott); Endo, p. 95.

1952 *Tsinania canens* (Walcott); Kobayashi, p. 150, pl. 13, figs 1–8, text-fig. 2.

1957 *Tsinania canens* (Walcott); Lu, p. 269, pl. 147, figs 9, 10.

1965 *Tsinania canens* (Walcott); Lu *et al.*, p. 341, pl. 63, figs 18–25.

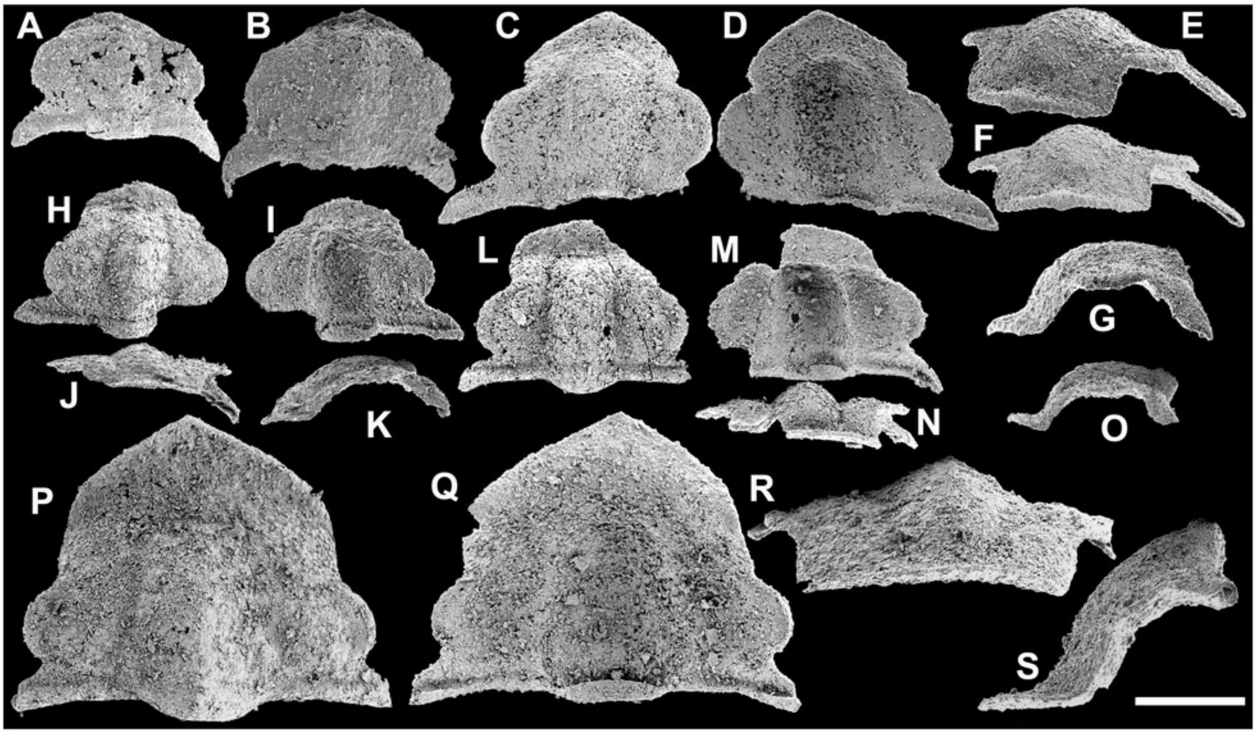

Fig. 5. Gumunsoia sp. 2, *?Mansuyia* sp. 1 and *Guangxiaspis* sp. 1 from Hwajeol Formation, Sagundari section, Korea. **A**–**F**, *Gumunsoia* sp. 2. **A**, Dorsal view of cranidium, KOPRIF 1095. **B**, Dorsal view of cranidium, KOPRIF 1096. **C**–**G**, Dorsal, ventral, anterior-lateral, anterior and lateral views of cranidium, KOPRIF 1097. **H**–**O**, *?Mansuyia* sp. 1. **H**–**K**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF1098. **L**–**O**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF1099. **P**–**S**, *Guangxiaspis* sp. 1. **P**–**S**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF1100. Scale bar = 1 mm.

1987 *Tsinania canens* (Walcott); Zhang & Jell, p. 195, pl. 86, figs 12–16; pl. 87, figs 1–14; pl. 88, figs 1–13; pl. 89, fig. 5.
2007 *Tsinania canens* (Walcott); Sohn & Choi, p. 308, figs 6k–n.
2014 *Tsinania canens* (Walcott); Park *et al*., p. 277, fig. 7.

Material. Three hundred and four cranidia, 128 free cheeks, 57 thoracic segments and 337 pygidia including immature specimens.

Occurrence. CHBd01–CHBd10 of the Hwajeol Formation in the Sagundari section.

Remarks. A complete ontogenetic description of this species was given by Park & Choi (2009). There seems to be slight intraspecific variation according to stratigraphic occurrence. The pygidial spines of *T. canens* abruptly disappear during development (Park & Choi 2009). Those from the lower beds tend to have the pygidial spine disappearing later than those from the upper beds (compare Fig. 4V and 4W).

Family KAOLISHANIIDAE Kobayashi, 1955

Gumunsoia Park, Sohn & Choi, 2012

Type species. Gumunsoia triangularis Park, Sohn & Choi, 2012, Furongian, Taebaeksan Basin, Korea.

Gumunsoia sp. 2 (Fig. 5A–G)

Material. Two immature cranidia and a fragmentary cranidium.

Occurrence. CHBd03, 06 and 08 of the Hwajeol Formation in the Sagundari section.

Remarks. Park *et al*. (2012) established *Gumunsoia*, documenting two species, *G. triangularis* and *Gumunsoia* sp. 1 from the *Kaolishania* fauna of the upper part of the Sesong Formation, which underlies the Hwajeol Formation. The specimens from the *Asioptychaspis subglobosa* Zone are assignable to *Gumunsoia* in having an anteriorly pointed cranidial border and large palpebral lobes. The anterior cranidial margin is also comparable in having a triangular outline. However, the largest specimen of *Gumunsoia* sp. 2 (Fig. 5C) is distinguished from the other two species of *Gumunsoia* in having a more effaced surface and a glabella not abutting the anterior cranidial border.

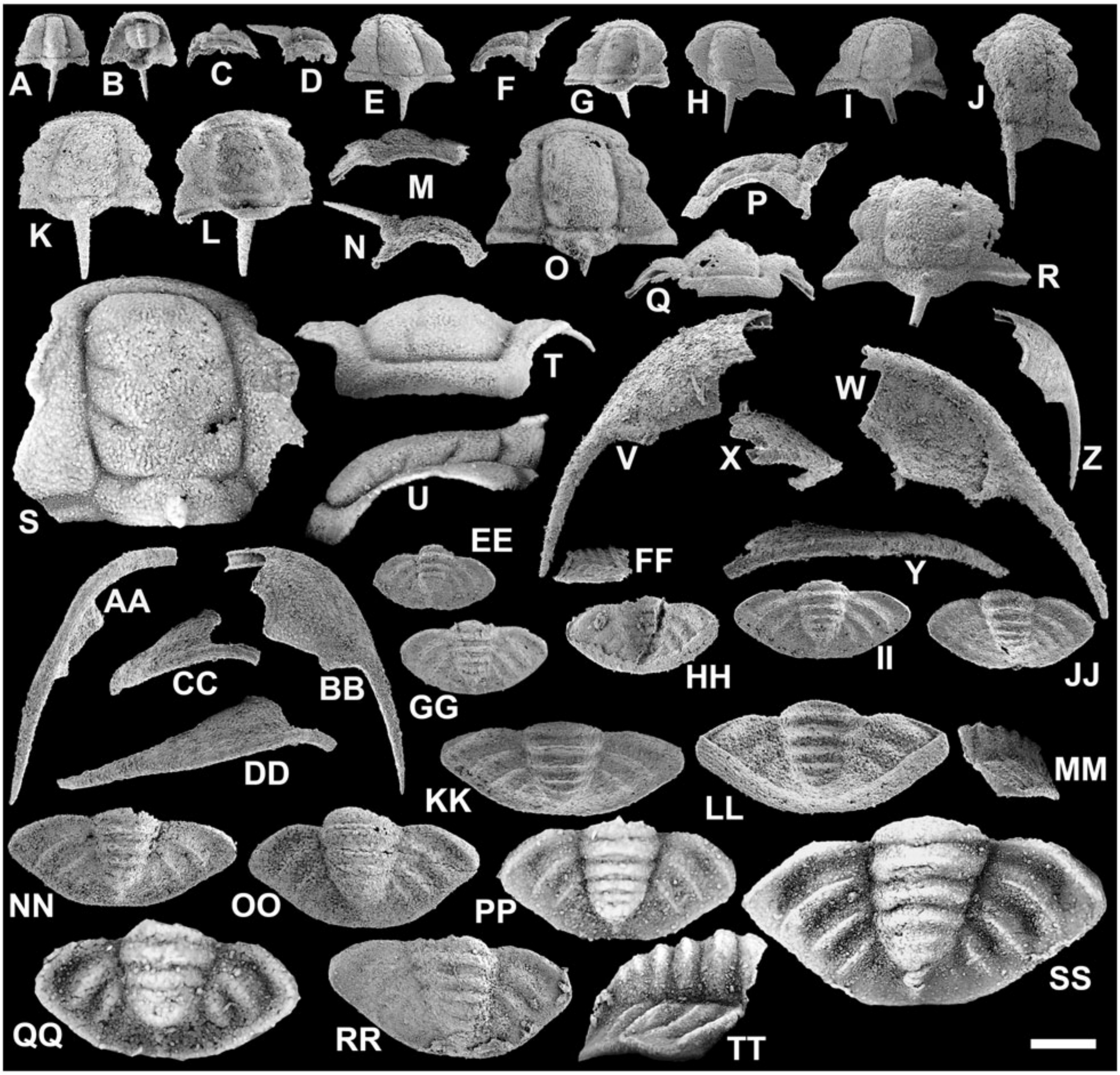

Fig. 6. Caznaia coreaensis sp. nov. from Hwajeol Formation, Sagundari section, Korea. **A**–**D**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1101. **E**–**G**, Dorsal, lateral and ventral views of cranidium, KOPRIF 1102. **H**, Dorsal view of cranidium, KOPRIF 1103. **I**, Dorsal view of cranidium, KOPRIF 1104. **J**, Dorsal view of cranidium, KOPRIF 1105. **K**–**N**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1106. **O–Q**, Dorsal, lateral and anterior view of cranidium, KOPRIF 1107. **R**, Dorsal view of cranidium, KOPRIF 1108. **S**–**U**, Dorsal, anterior and lateral views of cranidium, KOPRIF 1109. **V**–**Y**, Dorsal, ventral, anterior and lateral views of free cheek, KOPRIF 1110. **Z**, Dorsal view of free cheek, KOPRIF 1111. **AA**–**DD**, Ventral, dorsal, anterior and lateral views of free cheek, KOPRIF 1112. **EE**, Dorsal view of pygidium, KOPRIF 1113**. FF**–**HH**, Lateral, dorsal and ventral views of pygidium, KOPRIF 1114. **II**, Dorsal view of pygidium, KOPRIF 1115. **JJ**, Dorsal view of pygidium, KOPRIF 1116. **KK**–**MM**, Dorsal, ventral and latertal views of pygidium, KOPRIF 1117. **NN**, Dorsal view of pygidium, KOPRIF 1118. **OO**, Dorsal view of pygidium, KOPRIF 1119. **PP**, Dorsal view of pygidium, KOPRIF 1120. **QQ**, Dorsal view of pygidium, KOPRIF 1121. **RR**, Dorsal view of pygidium, KOPRIF 1122. **SS**–**TT**, Dorsal and lateral views of pygidium, KOPRIF 1123. Scale bar = 1 mm.

Mansuyia Sun, 1924

Type species. Mansuyia orientalis (Grabau) Sun, 1924 from the Fengshan Stage in the Yehli Limestone, China.

?**Mansuyia** sp. 1 (Fig. 5H–O)

Material. Two immature cranidia.

Occurrence. CHBd08 of the Hwajeol Formation in the Sagundari section.

Remarks. The larger of the two specimens (Fig. 5L) is reminiscent of specimens of '*Mansuyia* cf. *orientalis*' Sun, 1924 reported from Queensland, Australia, by Shergold (1975). *Mansuyia orientalis* was originally reported from North China, and most species of this genus were reported from the *Kaolishania* Zone of North China; only *M. taianfuensis* (Endo 1939) occurs in the lowermost part of the *Asioptychaspis–Tsinania* Zone (Park *et al*., 2014). Park *et al*. (2014) documented the biostratigraphic ranges of four *Mansuyia* species in detail, and revealed that *M. orientalis* occurs well below

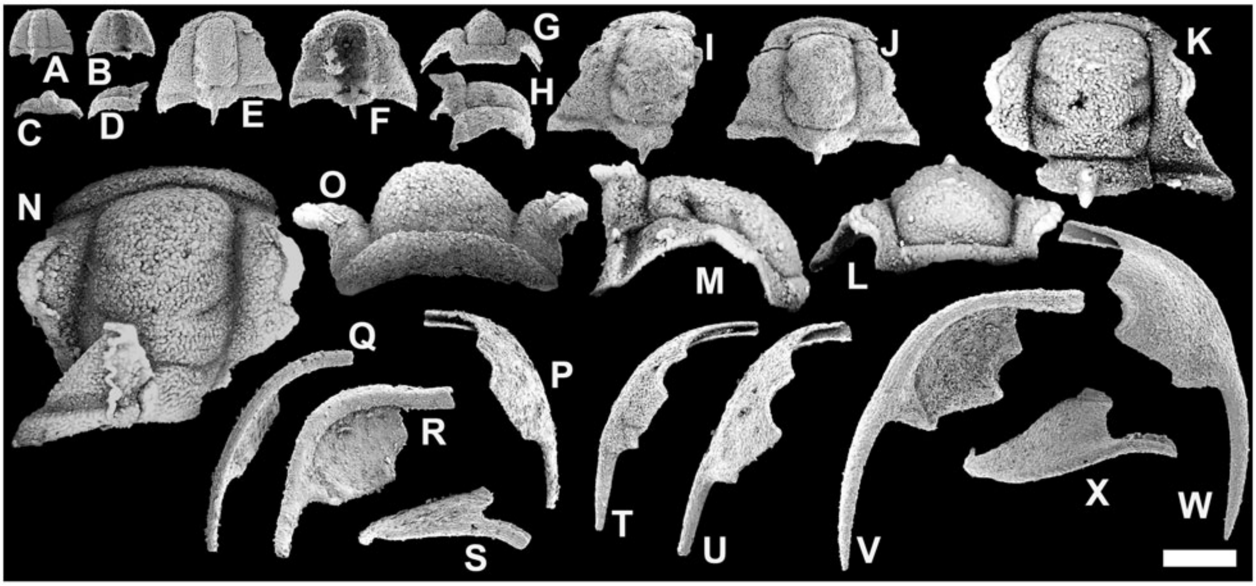

Fig. 7. ?*Saukia aojii* (Kobayashi, 1933) from Hwajeol Formation, Sagundari section, Korea. **A**–**D**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1124. **E**–**H**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1125. **I**, Dorsal view of cranidium, KOPRIF 1126. **J**, Dorsal view of cranidium, KOPRIF 1127. **K**–**M**, Dorsal, anterior and lateral views of cranidium, KOPRIF 1128. **N**–**O**, Dorsal and anterior views of cranidium, KOPRIF 1129. **P**–**S**, Dorsal, ventral, oblique ventral and anterior views of free cheek, KOPRIF 1130. **T**, Dorsal view of free cheek, KOPRIF 1131. **U**, Dorsal view of free cheek, KOPRIF1132. **V**–**X**, Ventral, dorsal and anterior views of free cheek, KOPRIF 1133. Scale bar = 1 mm.

the base of the *Asioptychaspis*–*Tsinania* Zone. The specimens of '*Mansuyia* cf. *orientalis*' from Queensland are morphologically distinguished from the specimens of *M. orientalis* from North China in having more posteriorly situated palpebral lobes and more slender and less convex pygidial spines. In addition, '*Mansuyia* cf. *orientalis*' occurs in the Payntonian Stage, which is stratigraphically much younger than the *Kaolishania* Zone of North China. Therefore, the taxonomic assignment of '*Mansuyia* cf. *orientalis*' from Queensland needs re-evaluation. The immature cranidia from the *Asioptychaspis subglobosa* Zone are provisionally assigned to *Mansuyia* under open nomenclature, based on their similarity to '*Mansuyia* cf. *orientalis*' from Queensland.

Guangxiaspis Zhou *in* Zhou *et al*., 1977

Type species. Guangxiaspis guangxiensis Zhou in Zhou *et al*., 1977, late Furongian, Hewen, Jingxi County, Guangxi Province, China.

Remarks. Zhou *et al*. (1977) regarded the familial assignment of this genus as uncertain. Later, Jell & Adrain (2003) assigned it to Pterocephaliidae Kobayashi, 1935. Recently, Zhu *et al*. (2010) provided a detailed morphological description of *Guangxiaspis* and assigned it to Kaolishaniidae.

Guangxiaspis sp. 1 (Fig. 5P–S)

Material. A single cranidium.

Occurrence. CHBd08 of the Hwajeol Formation in the Sagundari section.

Remarks. Zhu *et al*. (2010) noted that *Anhuiaspis* Qian & Qiu *in* Qiu *et al*., 1983 is quite similar to *Guangxiaspis*, but the latter has palpebral lobes situated more anteriorly. The single cranidium from the Hwajeol Formation is assigned to *Guangxiaspis* based on the position of the palpebral lobes. Two species have been established for this genus: *G. guangxiensis* Zhou in Zhou *et al*., 1977 and *G. midonodus* Qian in Qiu *et al*., 1983. Both species have divergent forward anterior branches of the facial sutures, whereas those of the cranidium from the Hwajeol Formation are slightly convergent anteriorly. However, without more material, the cranidium is left under the open nomenclature. The other two species of *Guangxiaspis* have been documented from South China.

Family SAUKIIDAE Ulrich & Resser, 1930

Caznaia Shergold, 1975

Type species. Caznaia squamosa Shergold, 1975 from the pre-Payntonian B interval at Black Mountain (by original designation).

Remarks. Shergold (1975) gave a detailed diagnosis of this genus and established two species: i.e., *Caznaia squamosa* and *C. sectatrix*. *Caznaia sectatrix* is distinguished from *C. squamosa* in having more anteriorly situated palpebral lobes, which result in the longer postocular area.

Caznaia coreaensis sp. nov. (Fig. 6)

1933 *Asioptychaspis subglobosa* Sun; Kobayashi, p. 118, pl. 12, fig. 7, not 1–6.
2007 *Asioptychaspis subglobosa* (Sun); Sohn & Choi, p. 304, figs 4s, t, not 4e–r.

Type material. Holotype, KOPRIF1107 (Fig. 6O–Q); paratypes, KOPRIF1109 (Fig. 6S–U); *Asioptychaspis subglobosa* Zone, lower part of the Hwajeol Formation, Sagundari section, Taebaeksan Basin, Korea; middle Furongian.

Etymology. Referring to the Latin name of Korea.

Diagnosis. A species of *Caznaia* with a preglabellar area less than one tenth of the cranidial length and a short occipital spine.

Description. Cranidium trapezoidal in outline with moderately granulated surface. Glabella outline barrel-shaped, *ca* 70% of cranidial length, *ca* 50% of palpebral cranidial width, defined by moderately deep axial furrow; S1 and S2 shallow, running adaxially obliquely backward. Occipital ring subrectangular to weakly semicircular with a short occipital spine, defined by moderately incised occipital furrow. Preglabellar area *ca* 7% of the cranidial length, flat to weakly convex. Anterior cranidial margin weakly rounded. Palpebral lobes *ca* 30% of cranidial length, located anterior to glabellar midpoint, defined by weakly impressed palpebral furrow; eye ridges absent. Posterior fixigenal field long, posterior border widening abaxially, defined by moderately incised posterior border furrow. Anterior branch of facial suture short, divergent, convex; posterior branch of facial suture long, weakly curved.

Free cheek with moderately wide and weakly convex genal field. Lateral border furrow weakly recognizable only in the anterior; eye socle narrow, defined by shallow eye socle furrow. Genal spine as long as genal field length. Cephalic doublure short, convex, slightly curved.

Pygidium semi-elliptical in outline. Length *ca* 50% of width. Axis *ca* 33% of pygidial width, tapering backward, comprising four axial rings and a terminal piece, not reaching to posterior margin. A weak postaxial ridge is present. Pleural field weakly convex; pleural furrow wide and shallow; interpleural margin is marked by a sharp ridge.

Material. Twenty-one cranidia, four free cheeks and 17 pygidia including immature specimens.

Occurrence. CHBd03–CHBd10 of the Hwajeol Formation in the Sagundari section.

Ontogeny. The immature cranidia smaller than 2.5 mm in length invariably have a prominent occipital spine (Fig. 6A–N, R). However, the occipital spine is very small in the largest cranidium (Fig. 6S). The glabella is slender and tapering forward in the smallest cranidia (Fig. 6A), and becomes broader and parallel-sided in larger cranidia (Fig. 6E–S).

Remarks. The new species has a more elongated glabella and divergent anterior branches of the facial suture compared with other representatives of the genus. The second largest cranidium (Fig. 6O) may retain some immature morphological features. For example, the occipital spine of the holotype is relatively longer than that of the largest cranidium (Fig. 6Q). However, because the largest cranidium is fragmentary, and the second largest cranidium is intact, the second largest cranidium has been designated as the holotype.

Kobayashi (1933) mistakenly assigned a pygidium of this species to *Asioptychaspis subglobosa* (Sun, 1924). Sohn & Choi (2007) followed Kobabyashi's identification on the pygidium of *A. subglobosa*, assigning the pygidia of this species to *A. subglobosa*. Kobayashi's (1933, pl. 12, fig. 7) record indicates that this species also occurs in the *Asioptychaspis–Tsinania* Zone of North China.

Saukia Walcott, 1914

Type species. Dikelocephalus lodensis Whitfield, 1880 from the Lodi Shale, Wisconsin (by original designation).

?**Saukia aojii** (Kobayashi, 1933) (Fig. 7)

1933 *Asioptychaspis subglobosa* Sun; Kobayashi, p. 118, pl. 12, fig. 7, not 1–6.
1933 *Saukia aojii* Kobayashi, p. 127, pl. 13, fig. 1.
1933 *Tellerina paichraensis* Kobayashi, p. 130, pl. 13, fig. 9.
1965 *Saukia* (?) *aojii* Kobayashi; Lu in Lu *et al.*, p. 440, pl. 86, fig. 5.
2007 *Asioptychaspis subglobosa* (Sun); Sohn & Choi, p. 304, figs 4s, t, not 4e–r.

Material. Fifteen cranidia, four free cheeks.

Occurrence. CHBd01, 03, 05, 08 and 10 of the Hwajeol Formation in the Sagundari section.

Remarks. The assignment of this species to *Saukia* is questionable. This species does not have a deeply incised S1 transglabellar furrow, which is a characteristic of *Saukia*; hence it is placed under open nomenclature. The immature cranidia of this species are similar to those of *Caznaia coreaensis*, but are distinguished in having more convex cranidia and lacking the long occipital spine.

Family PTYCHASPIDIDAE Raymond, 1924

Asioptychaspis Kobayashi, 1933

Type species. Ptychaspis ceto Walcott, 1905 from the Chaumitien (Chaomidian) Formation of Shandong Province, North China.

Other species. Sohn & Choi (2007) listed eight other species of *Asioptychaspis* from North China: *Ptychaspis calyce* (Walcott, 1905); *Ptychaspis cacus* Walcott, 1905; *Ptychaspis calchas* Walcott, 1905; *Ptychaspis subglobosa* Sun, 1924; *Ptychaspis brevicus* Sun, 1935; *Ptychaspis shansiensis* Sun, 1935; *Ptychaspis*? *fengshanensis* Sun, 1935; and *Ptychaspis asiatica* Resser & Endo, 1937 in Endo & Resser, 1937. However, some of these species were established using poorly preserved specimens, and thus likely to be synonyms of the others. A rigorous taxonomic revision is needed for the material from North China.

Remarks. Sohn & Choi (2007) discussed this genus in detail; they emphasized the differentiation of *Asioptychaspis* from *Ptychaspis* Hall, 1863, which is in agreement with Westrop (1986). The generic concept of Westrop (1986) and Sohn & Choi (2007) is followed here.

Asioptychaspis subglobosa (Sun, 1924) (Fig. 8)

1924 *Ptychaspis subglobosa* Sun, p. 72, pl. 5, figs 3a–d.
1933 *Asioptychaspis subglobosa* Sun; Kobayashi, p. 118, pl. 12, figs 1–6, not 7.
?1933 *Asioptychaspis sphaira* Kobayashi, p. 119, pl. 12, figs 12, 13.
1935 *Ptychaspis* cf. *subglobosa* Sun; Sun, p. 28, pl. 5, fig. 13.
1937 *Ptychaspis sphaerica* Resser & Endo; Endo & Resser, p. 273, pl. 55, figs 10–13.
1942 *Asioptychaspis chiliensis* Resser, p. 7.
1957 *Ptychaspis subglobosa* Sun; Lu, p. 286, pl. 148, fig. 9.
1965 *Ptychaspis sphaerica* Resser & Endo; Lu *et al.*, p. 427, pl. 82, figs 13–16.
1965 *Asioptychaspis sphaira* Lu *et al.*, p. 427, pl. 82, figs 17–19.
1987 *Ptychaspis subglobosa* Sun; Zhang & Jell, p. 227, pl. 112, figs 6–11.
2007 *Asioptychaspis subglobosa* (Sun); Sohn & Choi, p. 304, figs 4e–r, not 4s, t.

Material. More than 500 cranidia, 133 free cheeks, 55 thoracic segments and 273 pygidia including immature specimens.

Occurrence. CHBd01–CHBd10 of the Hwajeol Formation in the Sagundari section.

Remarks. A complete ontogenetic description of this species was given by Park & Choi (2010).

Family RICHARDSONELLIDAE Raymond, 1924

Haniwa Kobayashi, 1933

Type species. Haniwa sosanensis Kobayashi, 1933 from the *Tsinania* Zone of the Chosan area, Korea.

Haniwa quadrata Kobayashi, 1933 (Fig. 9)

1933 *Haniwa quadratus* Kobayashi, p. 149, pl. 15, figs 7, 8.
2007 *Haniwa sosanensis* (Sun); Sohn & Choi, p. 310, figs 6s, not 6p–r.

Diagnosis. A species of *Haniwa* that has a divergent forward anterior branch of the facial suture.

Material. One hundred and forty cranidia, 44 free cheeks, 28 thoracic segments and 127 pygidia including immature specimens.

Occurrence. CHBd01–CHBd10 of the Hwajeol Formation in the Sagundari section.

Remarks. A complete ontogenetic description of this species was given by Park & Choi (2011a) and is not repeated here. As pointed out by Park & Choi (2011a), Sohn & Choi (2007) mistakenly regarded all the *Haniwa* specimens from both the *Asioptychaspis* Zone and the overlying *Quadraticephalus* Zone as *H. sosanensis* Kobayashi, 1933. However, *H. sosanensis* has a parallel-sided anterior branch of the facial suture, whereas the cranidia from the *Asioptychaspis subglobosa* Zone invariably have forward divergent anterior branches of the facial suture.

Family DOKIMOCEPHALIDAE Kobayashi, 1935

Wuhuia Kobayashi, 1933

Type species. Solenopleura belus Walcott, 1905 from the Fengshan Formation, Shandong, North China.

Wuhuia belus (Walcott, 1905) (Fig. 10)

1905 *Solenopleura belus* Walcott, p. 90.
1913 *Conocephalina belus* (Walcott); Walcott, p. 138, pl. 13, figs 12, 12a.
1933 *Wuhuia belus* (Walcott); Kobayashi, p. 145, pl. 15, fig. 1.

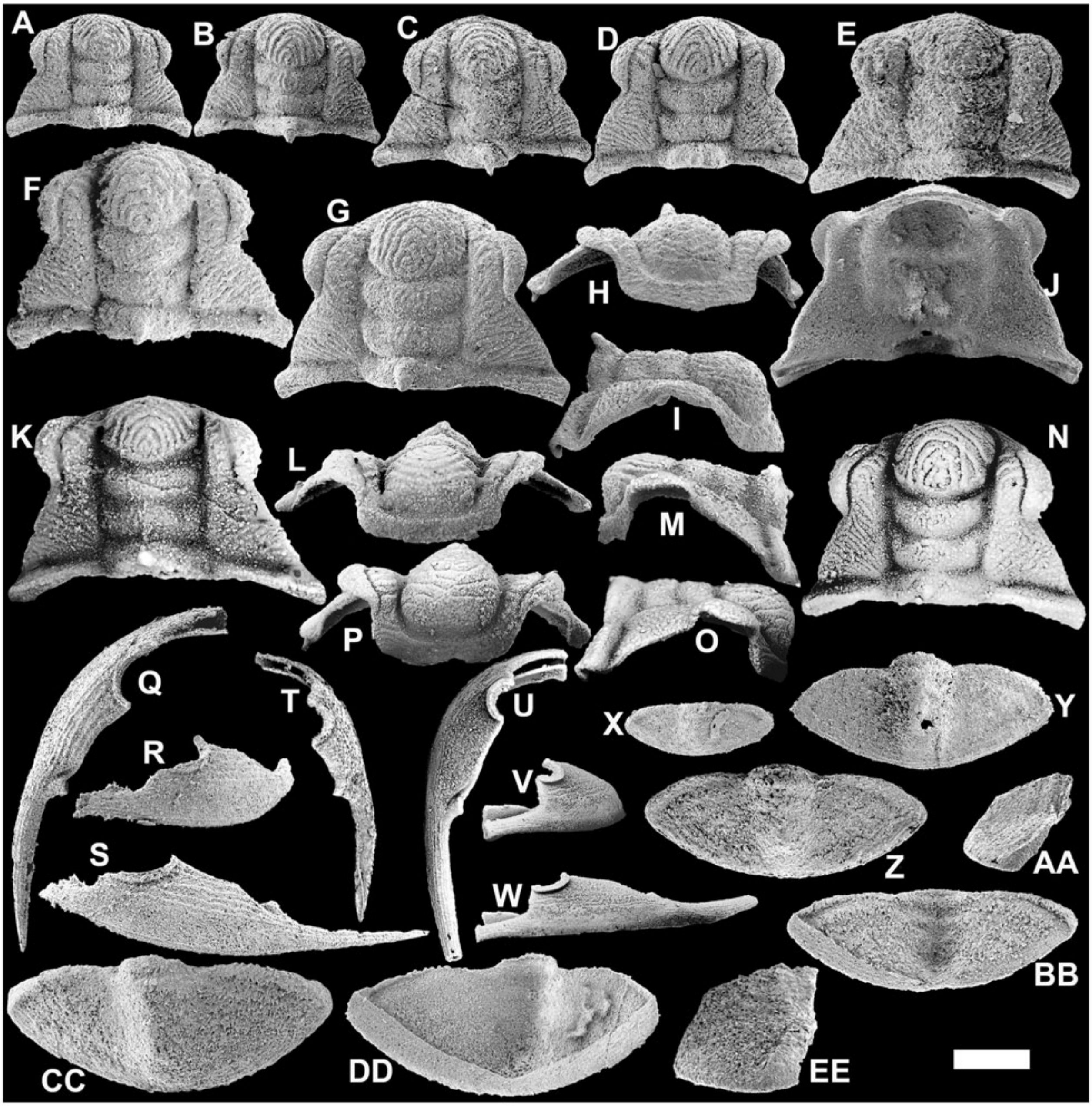

Fig. 8. Asioptychaspis subglobosa (Sun, 1924) from Hwajeol Formation, Sagundari section, Korea. **A**, Dorsal view of cranidium, KOPRIF 1134. **B**, Dorsal view of cranidium, KOPRIF 1135. **C**, Dorsal view of cranidium, KOPRIF 1136. **D**, Dorsal view of cranidium, KOPRIF 1137. **E**, Dorsal view of cranidium, KOPRIF 1138. **F**, Dorsal view of cranidium, KOPRIF 1139. **G–J**, Dorsal, anterior, latertal and ventral views of cranidium, KOPRIF 1140. **K**–**M**, Dorsal, anterior and lateral views of cranidium, KOPRIF 1141. **N**–**P**, Dorsal, lateral and anterior views of cranidium, KOPRIF 1142. **Q–S**, Dorsal, anterior and lateral views of free cheek, KOPRIF 1143. **T**, Dorsal view of free cheek, KOPRIF 1144. **U**–**W**, Dorsal, anterior and lateral views of free cheek, KOPRIF 1145. **X**, Dorsal view of pygidium, KOPRIF 1146. **Y**, Dorsal view of pygidium, KOPRIF 1147. **Z**–**BB**, Dorsal, lateral and ventral views of pygidium, KOPRIF 1148. **CC**–**EE**, Dorsal, ventral and lateral views of pygidium, KOPRIF 1149. Scale bar = 1 mm for **A–J** and **Q–DD**, and 1.25 mm for **K–P**.

1965 *Wuhuia belus* (Walcott); Lu *et al*., p. 436, pl. 85, figs 9, 10, 13, not 11, 12.

1987 *Wuhuia belus* (Walcott); Zhang & Jell, p. 239, pl. 118, fig. 15, pl. 119, figs 1, 2.

Description. Cranidium highly convex, subtriangular in outline, as long as wide. Glabella convex, slightly tapering forward, constricted at S3, *ca* 65% of cranidial length, *ca* 60–65% of palpebral width, defined by deeply impressed axial furrows and moderately incised preglabellar furrow; S1 and S2 well incised, S3 weakly recognizable. Preglabellar area *ca* 12% of cranidial length, downsloping forward. Anterior border absent; anterior cranidial margin rounded. Palpebral lobes long and narrow, *ca* 50% of glabellar length, defined by weakly incised palpebral furrow; anterior and posterior

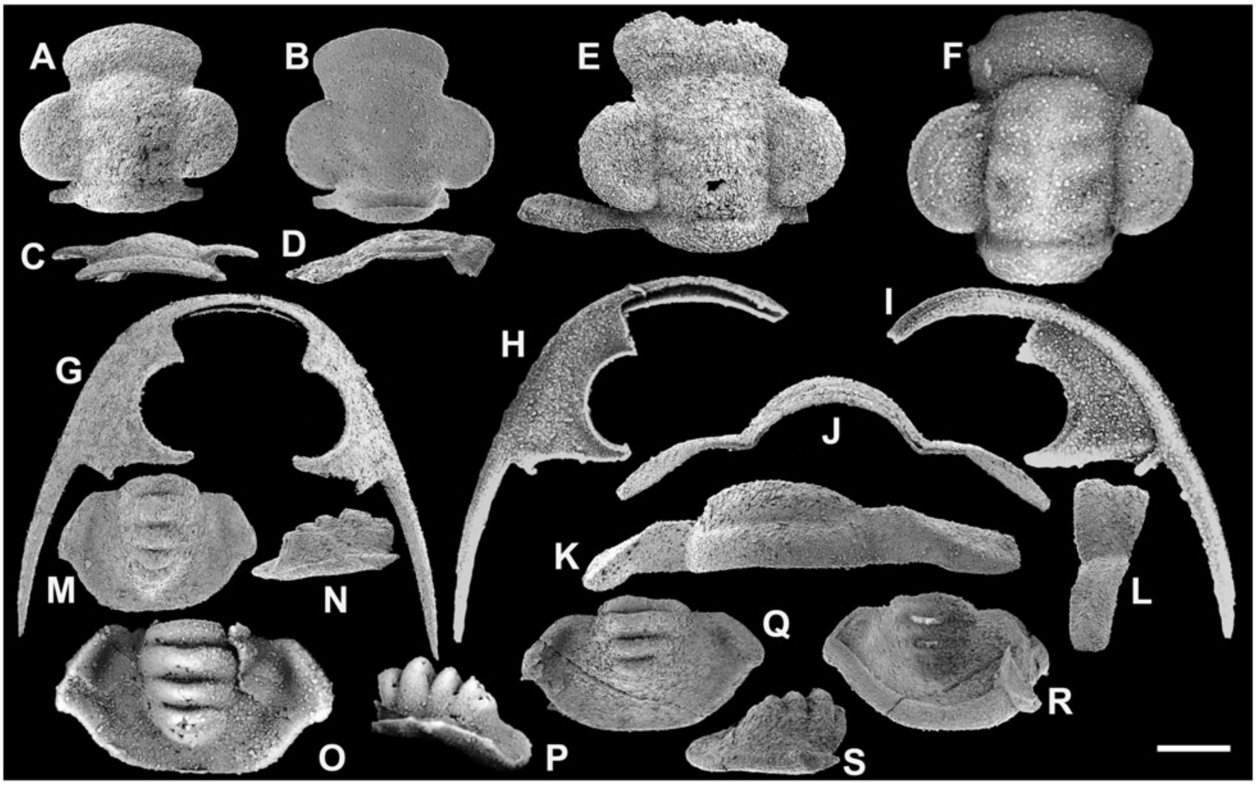

Fig. 9. Haniwa quadrata (Kobayashi, 1933) from Hwajeol Formation, Sagundari section, Korea. **A**–**D**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1150. **E**, Dorsal view of cranidium, KOPRIF 1151. **F**, Dorsal view of cranidium, KOPRIF 1152. **G**, Dorsal view of free cheek, KOPRIF 1153. **H**–**I**, Dorsal and ventral view of free cheek, KOPRIF 1154. **J**–**L**, Anterior, dorsal and lateral view of free cheek, KOPRIF 1155. **M**–**N**, Dorsal and lateral views of pygidium, KOPRIF 1156. **O**–**P**, Dorsal and lateral views of pygidium, KOPRIF 1157. **Q**–**S**, Dorsal, ventral and lateral views of pygidium, KOPRIF 1158. Scale bar = 1 mm for **A–E** and **G–S**, and 1.25 for **F**.

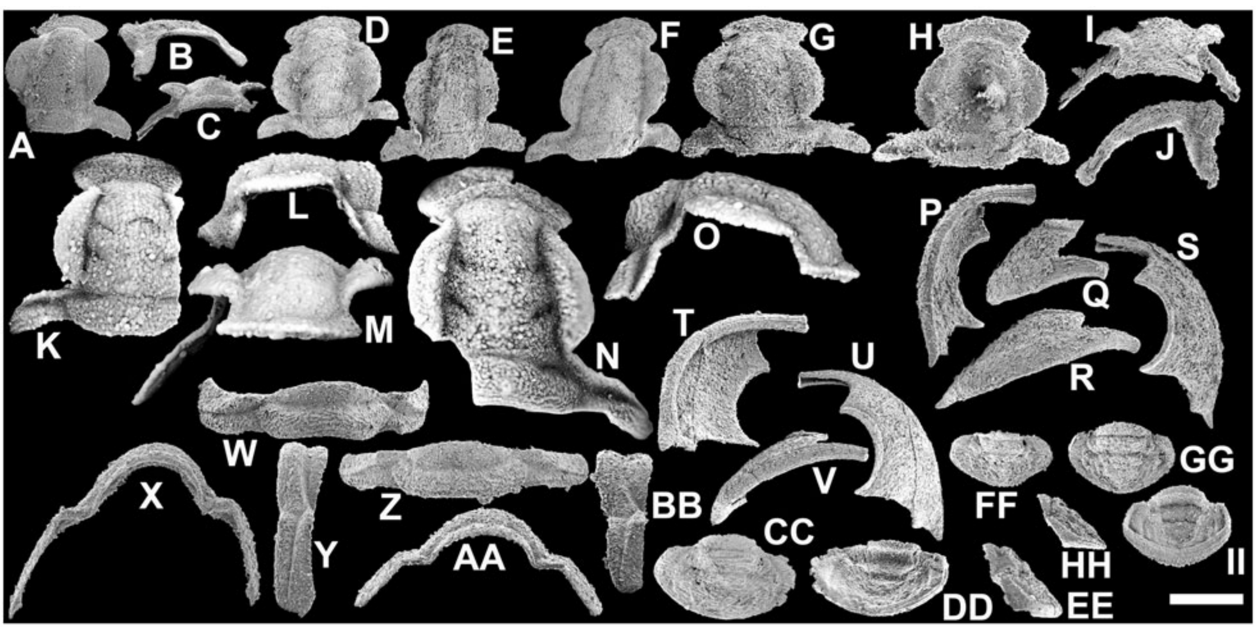

Fig. 10. Wuhuia belus (Walcott, 1905) from Hwajeol Formation, Sagundari section, Korea. **A**–**C**, Dorsal, lateral and anterior views of cranidium, KOPRIF 1159. **D**, Dorsal view of cranidium, KOPRIF 1160. **E**, Dorsal view of cranidium, KOPRIF 1161. **F**, Dorsal view of cranidium, KOPRIF 1162. **G**–**J**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1163. **K–M**, Dorsal, lateral and anterior views of cranidium, KOPRIF 1164. **N**–**O**, Dorsal and lateral views of cranidium, KOPRIF 1165. **P**–**S**, Ventral, anterior, lateral and dorsal views of free cheek, KOPRIF 1166. **T**–**V**, Ventral, dorsal and anterior views of free cheek, KOPRIF 1167. **W**–**Y**, Dorsal, anterior and lateral views of thoracic segment, KOPRIF 1168. **Z**–**BB**, Dorsal, anterior and lateral views of thoracic segment, KOPRIF 1169. **CC**–**DD**, Dorsal and ventral views of pygidium, KOPRIF 1170. **EE**–**FF**, Lateral and dorsal views of pygidium, KOPRIF 1171. **GG**–**II**, Dorsal, lateral and ventral views of pygidium, KOPRIF 1172. Scale bar = 1 mm.

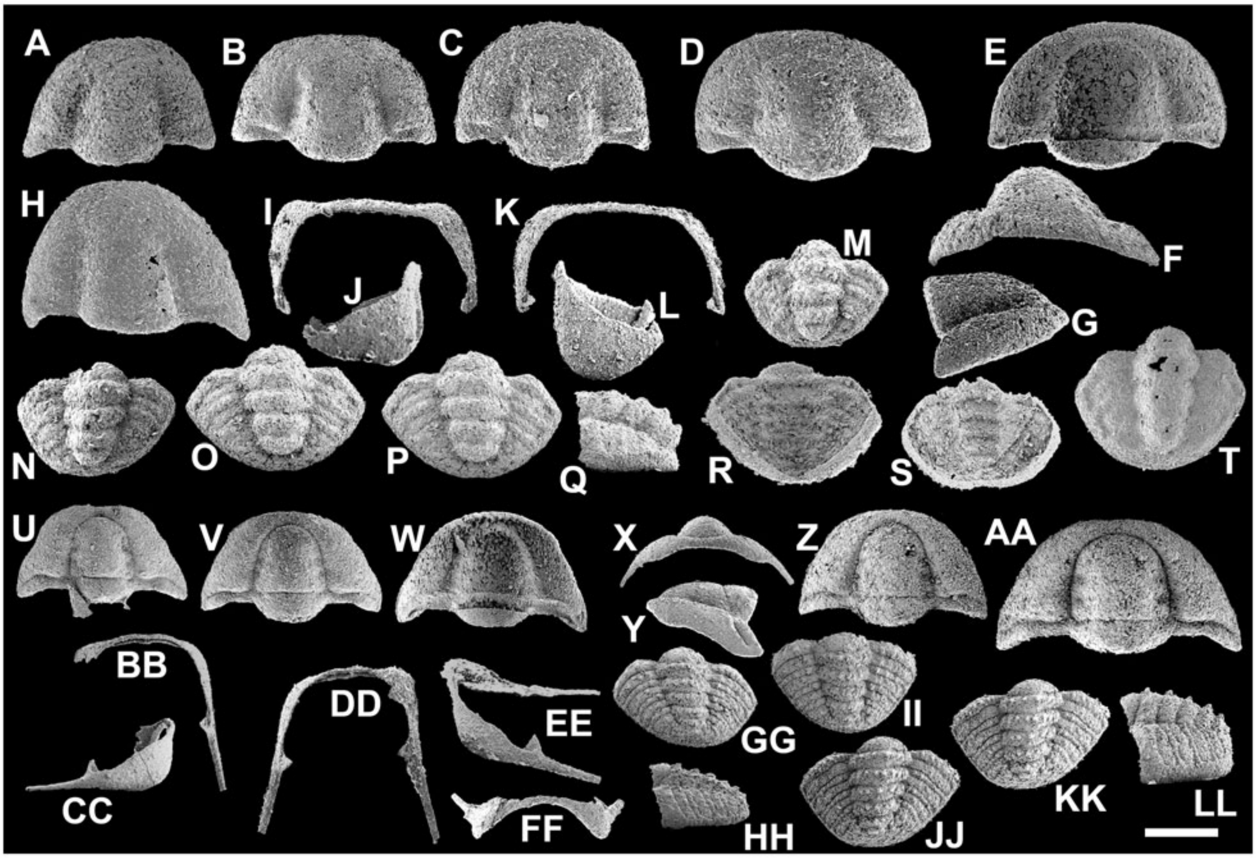

Fig. 11. Koldinioidia choii sp. nov. and *Akoldinioidia latus* sp. nov. from Hwajeol Formation, Sagundari section, Korea. **A**–**T**, *Koldinioidia choii*. **A**, Dorsal view of cranidium, KOPRIF 1173. **B**, Dorsal view of cranidium, KOPRIF 1174. **C**, Dorsal view of cranidium, KOPRIF 1175. **D**–**G**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1176. **H**, Dorsal view of cranidium, KOPRIF 1177. **I**–**J**, Dorsal and lateral views of free cheek, KOPRIF 1178. **K**–**L**, Dorsal and lateral views of free cheek, KOPRIF 1179. **M**, Dorsal view of pygidium, KOPRIF1180. **N**, Dorsal view of pygidium, KOPRIF 1181. **O**, Dorsal view of pygidium, KOPRIF 1182. **P**–**R**, Dorsal, lateral and ventral views of pygidium, KOPRIF 1183. **S**, Ventral view of pygidium, KOPRIF 1184. **T**, Dorsal view of pygidium, KOPRIF 1185. **U**–**LL**, *Akoldinioidia latus*. **U**, Dorsal view of cranidium, KOPRIF 1186. **V**–**Y**, Dorsal, ventral, anterior and lateral views of cranidium, KOPRIF 1187. **Z**, Dorsal view of cranidium, KOPRIF 1188. **AA**, Dorsal view of cranidium, KOPRIF 1189. **BB**–**CC**, Dorsal and lateral view of free cheek, KOPRIF 1190. **DD**–**FF**, Dorsal, oblique lateral and anterior view of free cheek, KOPRIF 1191. **GG**–**HH**, Dorsal and lateral views of pygidium, KOPRIF 1192. **II**, Dorsal view of pygidium, KOPRIF 1193. **JJ**, Dorsal view of pygidium, KOPRIF 1194. **KK**–**LL**, Dorsal and lateral views of pygidium, KOPRIF 1195. Scale bar = 0.6 mm for **A–T**, and 1 mm for **U–LL**.

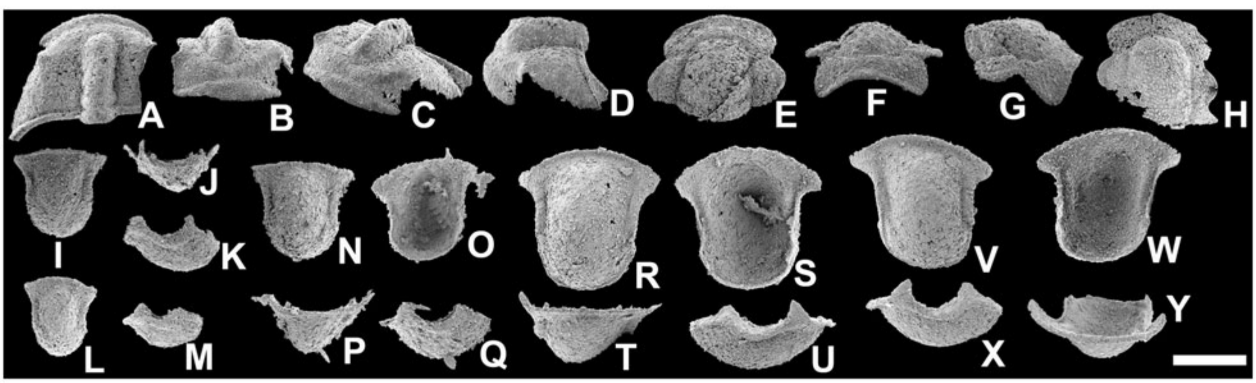

Fig. 12. Baikadamaspis sp. 2, indeterminate cranidium 1 and indeterminate hypostome. **A**–**D**, *Baikadamaspis* sp. 2. **A**–**D**, Dorsal, anterior, oblique anterior-lateral, lateral views of cranidium, KOPRIF 1196. **E**–**H**, Indeterminate cranidium 1. **E**–**G**, Dorsal, anterior and lateral views of cranidium, KOPRIF 1197. **H**, Dorsal view of cranidium, KOPRIF 1198. **I**–**Y**, Indeterminate hypostome. **I**–**K**, Dorsal, anterior and lateral views of hypostome, KOPRIF 1199. **L**–**M**, Dorsal and lateral views of hypostome, KOPRIF 1200. **N**–**Q**, Dorsal, ventral, anterior and lateral views of hypostome, KOPRIF 1201. **R**–**U**, Dorsal, ventral, anterior and lateral views of hypostome, KOPRIF 1202. **V**–**Y**, Dorsal, ventral, lateral and anterior view of hypostome, KOPRIF 1203. Scale bar = 1 mm for **A–G** and **I–Y**, and 1.7 mm for **H**.

tips of palpebral lobe abutting L4 and L1. Posterior fixigenal field very short; posterior border slightly longer (sag.) than posterior fixigenal field of cranidial length, delineated by deep and wide posterior border furrow. Anterior branch of facial suture strongly divergent forward; posterior branch of facial suture strongly divergent backward to nearly transverse.

Free cheek crescentic in outline; genal field broad and moderately downsloping abaxially; lateral border absent; genal spine very short; very narrow eye socle defined by slightly incised eye socle furrow.

Thoracic segments convex, axis *ca* 55% of transverse width. Those from anterior part of trunk (Fig. 10W–Y) more convex than those from posterior part of trunk (Fig. 10Z–AA); anterior lateral margin anteriorly pointed in dorsal view (Fig. 10W).

Pygidium semicircular in dorsal view, length *ca* 66% of width. Axis broad, 50–56% of pygidial width, strongly tapering backward; three axial rings and a terminal piece. Pleural furrows weakly incised, highly curved backward.

Material. Twenty-six cranidia, four free cheeks, five thoracic segments and six pygidia including immature specimens.

Occurrence. CHBd03–05 of the Hwajeol Formation in the Sagundari section.

Remarks. The correct free cheek, thoracic segments and pygidia for this species are documented for the first time. Given the length of the cephalic doublure in the free cheek, this trilobite may have had a ventral median suture.

Family SHUMARDIIDAE Lake, 1907

Koldinioidia Kobayashi, 1931 emend.

Type species. Koldinioidia typicalis Kobayashi, 1931, p. 187.

Emended diagnosis. A genus of the Shumardiidae with preglabellar furrow effaced or obliterated; anterolateral lobes poorly defined or absent.

Remarks. Zhu & Peng (2006) gave a diagnosis of the genus, which included 'pygidium lacking well-defined borders'. The pygidia of the new species in this study, however, have well-defined lateral borders in dorsal view. The overall generic concept and taxonomic history including the full synonym list of the genus were provided by Zhu & Peng (2006) and are not repeated here.

Koldinioidia choii sp. nov. (Fig.11A–T)

Type material. Holotype, KOPRIF1176 (Fig. 11D); paratypes, KOPRIF1173–1177 (Fig. 11A–C, H); *Asioptychaspis subglobosa* Zone, lower part of the Hwajeol Formation, Sagundari section, Taebaeksan Basin, Korea; middle Furongian.

Etymology. After Prof. Duck K. Choi in recognition of his contribution to trilobite studies in Korea.

Diagnosis. A species of *Koldinioidia* with a very broad-based glabella; the glabellar width is *ca* 50% of the cranidial width.

Description. Cranidium semicircular in outline. Glabella convex, weakly constricted, without preglabellar furrow; the glabellar width *ca* 50% of the cranidial width; axial furrows well incised; S1 and S2 weakly impressed in large cranidia. Occipital ring *ca* 30% of cranidial length; posterior margin curved posteriorly; occipital furrow weakly incised or obliterated. Anterior border absent. Palpebral lobes absent; palpebral ridges absent. Fixed cheek convex, narrow and peripherally downsloping. Facial suture straight in lateral view. Posterior border transverse, downsloping abaxially, becoming longer abaxially; posterior border furrow straight and clearly incised.

Free cheek anteriorly yoked with narrow doublure; genal field wide, strongly downsloping abaxially; frontal part of doublure highly arched upward in anterior view; genal spines absent.

Pygidium semicircular in outline; surface smooth. Axis tapering backwards with three axial rings and a terminal piece, *ca* 40% of pygidial width; axial furrows clearly incised; axial rings convex. Pleural region moderately convex; pleural furrow narrow and moderately incised; interpleural furrow narrow and weakly incised. Postaxial area smooth, downsloping almost perpendicularly in lateral view. Pygidial border narrow, defined by weakly incised border furrow.

Material. Thirty-seven cranidia, eight free cheeks, and 29 pygidia including immature specimens.

Occurrence. CHBd03, 04, 06, 08 and 10 of the Hwajeol Formation in the Sagundari section.

Remarks. This species is easily distinguishable from other species of *Koldinioidia* in having the broadest glabellar base. Although a preglabellar furrow is absent in dorsal view, the frontal margin of the glabella is recognizable in ventral view (Fig. 11E). This is in line with *Koldinioidia orientalis* (Mansuy, 1916), the internal mould of which shows a distinct preglabellar furrow (see Zhu & Peng 2006).

Akoldinioidia Zhou in Zhou & Zhang, 1984

Type species. Akoldinioidia pustulosa Zhou & Zhang, 1984, upper Cambrian of Lulong, Hebei, China (by original designation).

Akoldinioidia latus sp. nov. (Fig. 11U–LL)

1939 *Koldinioidia aspinosa* Endo, p. 9, pl. 1, fig. 23.
1987 *Koldinioidia aspinosa* Zhang & Jell, p. 243, pl. 119, figs 11, 12.

Etymology. From Latin *latus*, broad, referring to the broad-based glabella.

Diagnosis. A species of *Koldinioidia* with very broad-based glabella; the glabellar width is *ca* 40% of the cranidial width. S1 and S2 glabellar furrows are distinct.

Description. Cranidium trapezoidal in outline with broadly rounded anterior margin. Glabella broad based; glabellar width *ca* 40% of cranidial width; axial furrows deeply incised, extending to well-incised preglabellar furrow; S1 and S2 wide and shallowly impressed. Preglabellar field *ca* 10% of cranidial length. Anterior border absent. Palpebral lobes absent; palpebral ridges absent. Occipital ring *ca* 25% of cranidial length; posterior margin convex backwards; occipital furrow deeply incised. Fixed cheek convex, narrow and peripherally downsloping. Facial suture weakly sinuous in lateral view. Posterior border initially straight, but curved rearward, downsloping abaxially; posterior border furrow clearly incised.

Free cheek anteriorly yoked with narrow doublure; genal field wide, strongly downsloping peripherally. Frontal part of doublure highly arched upward in anterior view. Genal spines as long as cranidial length.

Pygidium inverted subtriangular in outline. Axis tapering backwards with five axial rings and a terminal piece, *ca* 40% of pygidial width; axial furrows clearly incised; axial rings sculptured with transversely arranged nodes. Pleural region convex and downsloping peripherally with five pleurae; pleural furrow and interpleural furrow narrow and deep; anterior pleural band narrower than posterior pleural band. Postaxial ridge absent. Postaxial area smooth, downsloping almost perpendicularly in lateral view. Pygidial border very narrow.

Material. Eighty-nine cranidia, eight free cheeks and 68 pygidia including immature specimens.

Occurrence. CHBd01–06, 08 and 10 of the Hwajeol Formation in the Sagundari section.

Remarks. The pygidial axial rings' sculpture incorporating transversely arranged nodes is reminiscent of that of *Elaphraella microforma* Lu & Qian, 1983 from the upper part of the underlying Sesong Formation (Park *et al.*, 2012). The outline of *Akoldinioidia latus* is similar to *Koldinioidia aspinosa* Kobayashi, 1933 documented from the *Tsinania canens* Zone (currently the *Asioptychaspis–Tsinania* Zone) of North China (Kobayashi, 1933, pl. 10, fig. 5). However, the single cranidium of *Koldinioidia aspinosa* documented by Kobayashi (1933) has a highly effaced preglabellar furrow. Although Peng (1992) transferred this species to *Akoldinioidia*, it is rather inappropriate to compare *Akoldinioidia latus* to *Akoldinioidia aspinosa*. Endo (1939) documented a single cranidium from the '*Tsinania* Zone' of Shandong, North China, and assigned it to *Koldinioidia aspinosa*, which has been re-illustrated by Zhang & Jell (1987, pl. 119, figs 11, 12). This cranidium is assignable to *Akoldinioidia latus* based on its broad-based glabella. Resser & Endo in Endo & Resser (1937) reported *Koldinioidia yenchouensis*, which has a preglabellar furrow, from the '*Tsinania* Zone' of Liaoning, North China (re-illustrated by Zhang & Jell, 1987, pl. 120, fig. 3), but the specimen is too poorly preserved for definitive identification. It is suggested that the specific concept of the *K. yenchouensis* be restricted to the characteristics of the holotype. *Koldinioidia trapezoidalis* Zhang in Qiu *et al.* (1983) was established on a single cranidium from the Fengshan Stage of North China. However, the cranidium has a more slender glabella, compared with *A. latus*.

Family HARPIDIDAE Whittington, 1950

Baikadamaspis Ergaliev, 1980

Type species. Baikadamaspis proprius Ergaliev, 1980 from the *Glyptagnostus reticulatus* to *Homagnostus longiformis* zones, Malyi Karatau, Kazakhstan (by original designation).

Baikadamaspis sp. 2 (Fig. 12A–D)

Material. A single fragmentary cranidium.

Occurrence. CHBd10 of the Hwajeol Formation in the Sagundari section.

Remarks. The single fragmentary cranidium is assignable to *Baikadamaspis* based on its convex cranidium with anteriorly situated diminutive palpebral lobes. However, it differs from other species of the genus in having a very slender glabella and a very short preglabellar area. Park & Choi (2011b) documented *Baikadamaspis* sp. 1 from the middle part (the *Fenghuangella laevis* Zone) of the Sesong Formation, which underlies the Hwajeol Formation; hence the specimen herein is assigned to *Baikadamaspis* sp. 2.

Unidentified sclerites

Indeterminate cranidium 1 (Fig. 12E–H)

Material. A fragmentary immature cranidium and a fragmentary mature cranidium.

Remarks. The anterior margin of these cranidia is arched dorsally in anterior view (Fig. 12F). The larger cranidium has a granular surface (Fig. 12H).

Occurrence. CHBd08 and 10 of the Hwajeol Formation in the Sagundari section.

Indeterminate hypostome 1 (Fig. 12I–Y)

Material. Twenty-three hypostomes.

Remarks. The smaller hypostomes have straighter anterior margins (Fig. 12I, L, N), compared with the larger hypostomes (Fig. 12R–W). Given the number of specimens, these hypostomes may be assignable to *Asioptychaspis subglobosa*. However, without definitive evidence, these hypostomes are left in open nomenclature.

Occurrence. CHBd03–10 of the Hwajeol Formation in the Sagundari section.

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