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Trilobite Biostratigraphy of the lower Paleozoic (Cambrian–Ordovician) Joseon Supergroup, Taebaeksan Basin, Korea

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Abstract: In Korea, trilobites are among the most intensively studied fossil groups in the past century and provide invaluable information about lower Paleozoic stratigraphy, paleogeography, and tectonics of the Korean Peninsula. Trilobites occur in the lower Paleozoic Joseon Supergroup of the Taebaeksan Basin which was part of the Sino-Korean Craton in the Paleozoic. The Joseon Supergroup is divided into the Taebaek, Yeongwol, and Mungyeong groups. The Taebaek and Yeongwol groups are richly fossiliferous, while the Mungyeong Group is poorly fossiliferous. Contrasting trilobite faunal contents of the Taebaek and Yeongwol groups resulted in two separate biostratigraphic schemes for the Cambrian–Ordovician of the Taebaeksan Basin. A total of 22 biozones or fossiliferous horizons were recognized in the Taebaek Group; 19 zones were established in the Yeongwol Group; and four biozones were known from the Mungyeong Group. These trilobite biozones of the Taebaeksan Basin indicate the Joseon Supergroup ranges in age from the Cambrian Series 2 to Middle Ordovician and can be correlated well with the formations of North China, South China, and Australia.

Key words: Trilobites, biostratigraphy, Cambrian–Ordovician, Taebaeksan Basin

1 Introduction

Trilobites are among the most abundant and diverse fossil groups in Korea. They occur in the lower Paleozoic Joseon Supergroup of the Taebaeksan Basin in the mid-eastern part of the Korean Peninsula (Fig. 1). The Joseon Supergroup is a mixed siliciclastic-carbonate succession that ranges in age from the Cambrian Series 2 to Middle Ordovician. The Joseon Supergroup has been traditionally divided into five groups, i.e., the Taebaek, Yeongwol, Yongtan, Pyeongchang, and Mungyeong groups (Kobayashi, 1966; Choi, 1998a; Choi and Chough, 2005). Recently, Choi (2014) suggested that the Yongtan and Pyeongchang groups can be treated as lateral equivalents of the Taebaek Group, while the Yeongwol and Mungyeong groups are maintained as distinct units (Fig. 2). The Taebaek and Yeongwol groups yield abundant and diverse trilobites, whereas the Mungyeong Group is poorly fossiliferous. A total of 224 species have been known from the Joseon Supergroup of the Taebaeksan Basin: 99 and 111 species were described from the Taebaek and Yeongwol groups, respectively, while 14 species were reported to occur in the Mungyeong Group (Kobayashi, 1966).

Most of the knowledge on the lower Paleozoic trilobite biostratigraphy of Korea was initially developed during the first half of 20th Century by a Japanese paleontologist, Teichii Kobayashi (Choi, 2007). In a comprehensive compilation of the Cambrian–Ordovician faunas of South Korea (Kobayashi, 1966), 16 trilobite biozones were recognized in the Taebaek Group, while nine and four biozones were established in the Yeongwol and Mungyeong groups, respectively. During the last quarter century, the Cambrian–Ordovician trilobites of the Joseon Supergroup have been intensively re-evaluated on the basis of new fossil collections, focusing mainly on systematic and taxonomic revision, refined biostratigraphic zonation, and paleogeographic and paleoecologic implications. The specific objective of this paper is to compile updated information on the trilobite biostratigraphy of the lower Paleozoic Joseon Supergroup, Taebaeksan Basin, Korea.

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2 Geology and Stratigraphy of the Taebaeksan Basin

There is a general consensus in that eastern Asia was formed by amalgamation of the Sino-Korean (or North China) and South China cratons in the Early Triassic (Dong et al., 2011; Wu and Zheng, 2013). The Sino-Korean Craton is composed of most of North China and parts of the Korean Peninsula, while the South China Craton comprises most of South China and middle part of the Korean Peninsula (Chough et al., 2000). The Korean Peninsula is divided tectonically into the northern, central, and southern blocks and is further subdivided into 11 tectonic provinces (Choi, 2009, 2014). Prior to the Mesozoic, the northern and southern blocks belonged to the Sino-Korean Craton, whilst the central block was part of the South China Craton.

The Taebaeksan Basin is a tectonic province occupying the northern part of the southern block of the Korean Peninsula and comprises mainly the lower Paleozoic Joseon Supergroup and upper Paleozoic Pyeongan Supergroup (Fig. 1). The Joseon Supergroup rests unconformably on the Paleoproterozoic basement composed largely of granitic gneiss and metasedimentary rocks, and is in turn overlain by the upper Paleozoic Pyeongan Supergroup. The two supergroups are separated by a disconformity representing a ca. 140-myr-long time span. The lower Paleozoic Joseon Supergroup consists predominantly of carbonate with subordinate sandstone and shale. Detailed description on the lithostratigraphy of the Joseon Supergroup was given by Choi and Chough (2005).

In the early Paleozoic, the Taebaeksan Basin was a shallow marine mixed siliciclastic-carbonate system with progressively greater depth of water to the west (Yeongwol and Mungyeong areas), as indicated by the occurrence of coarse-grained siliciclastic sedimentary successions (Jangsan and Myeonsan formations) along

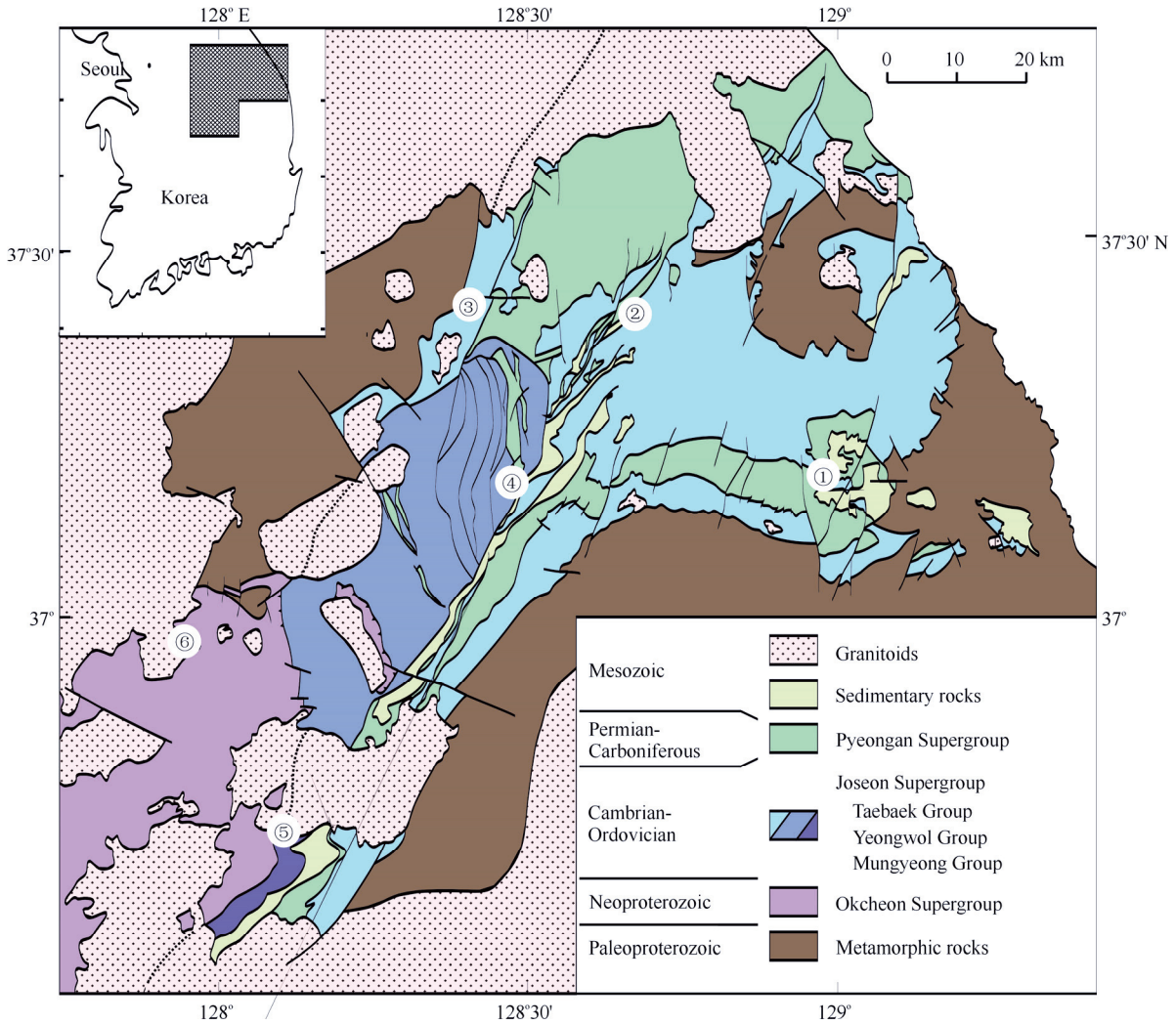

Fig. 1. Simplified geologic map of the Taebaeksan Basin, Korea. SKTL denotes the South Korean Tectonic Line (Chough et. al., 2000).
Circled numbers denote: ①, Taebaek; ②, Jeongseon; ③, Pyeongchang: ④, Yeongwol; ⑤, Mungyeong; ⑥, Chungju.

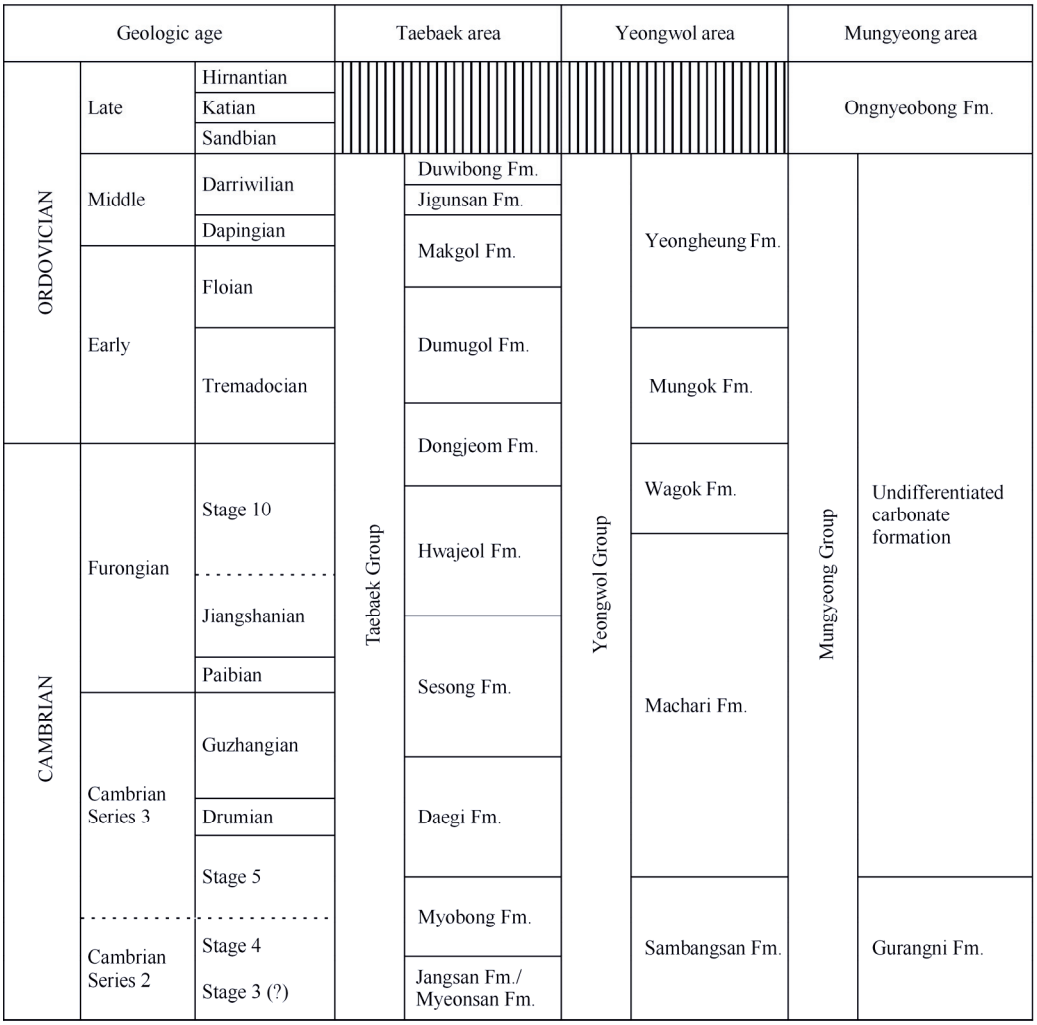

Fig. 2. Lithostratigraphic summary of the lower Paleozoic Joseon Supergroup in the Taebaeksan Basin, Korea (modified after Choi, 1998a).

the eastern margin of the Taebaeksan Basin (Chough et al., 2000). This siliciclastic-carbonate system continued throughout the Cambrian, but rapid accumulation of carbonate sediments in the Yeongwol area in the latest Cambrian resulted in forming a widespread carbonate platform across the Taebaeksan Basin. Accordingly, the Taebaeksan Basin had a shallow marine setting with shoals, lagoons, and tidal flats that persisted into the Early and Middle Ordovician (Choi et al., 2001). Early Paleozoic marine sedimentation ceased over much of the Taebaeksan Basin in the Late Ordovician, whilst Late Ordovician volcanism occurred in the Mungyeong area. The Late Ordovician volcanism has been interpreted to suggest the timing for breakup of the Sino-Korean Craton from core Gondwana by the end of Ordovician (Cho et al., 2014). Subsequently, the Taebaeksan Basin became emergent during the mid-Paleozoic until marginal marine to non-marine sedimentation of the Pyeongan Supergroup resumed in the late Carboniferous.

2.1 Taebaek Group

The Taebaek Group refers to the Cambrian–Ordovician succession that is exposed in the eastern and northern parts of the Taebaeksan Basin, bounded to the southwest by thrust faults (Choi and Chough, 2005; Fig. 1). It has been divided into, in ascending order, the Jangsan/Myeonsan, Myobong, Daegi, Sesong, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan, and Duwibong formations (Kobayashi, 1966; Choi, 1998a; Lee, 2014; Fig. 3). Sedimentological studies revealed that the Taebaek Group had formed in a low-relief, mixed carbonate-siliciclastic setting, influenced strongly by sea-level fluctuations (Choi et al., 2004a; Kwon et al., 2006 and references therein). A total of 22 trilobite biozones have been established within the Taebaek Group (Fig. 3) and constrain the geologic age of the group ranging from the Cambrian Series 2 (Cambrian Stage 4 or Stage 3) to Middle Ordovician (Darriwilian).

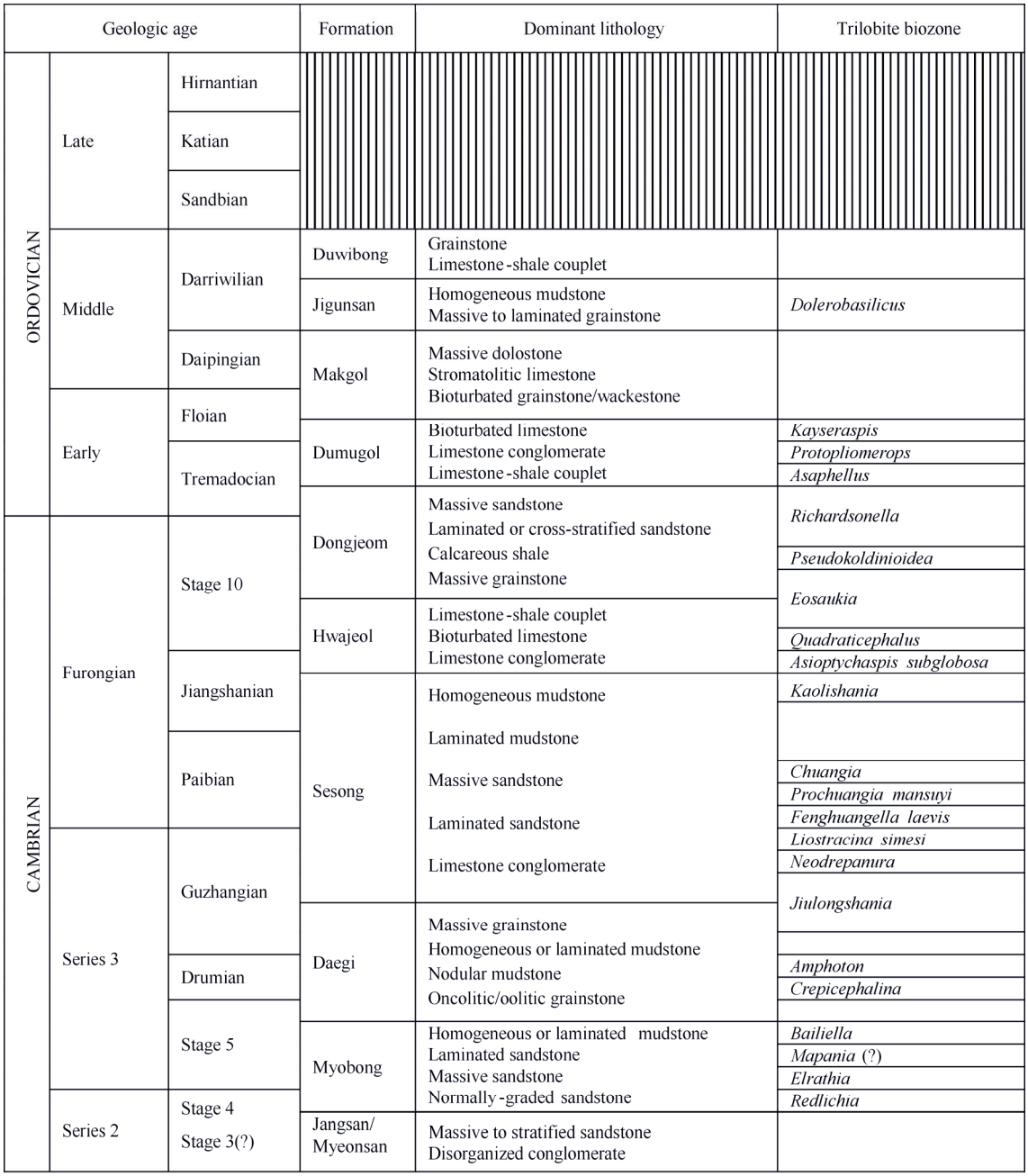

Fig. 3. Lithostratigraphic and biostratigraphic summary of the Taebaek Group, Taebaeksan Basin, Korea.

2.2 Yeongwol Group

The Yeongwol Group occupies the western half of the Taebaeksan Basin, bounded to the east by the Deokpori thrust, to the north by Sangni thrust, and to the west by the Bonghwajae thrust, and its geologic structure is largely governed by a number of imbricated thrust faults (Choi, 1998a; fig. 1). The Yeongwol Group is divided into, from oldest to youngest, the Sambangsan, Machari, Wagok, Mungok, and Yeongheung formations (Yosimura, 1940; Kobayashi, 1966; Choi, 1998a; fig. 4). The lowermost Sambangsan Formation consists exclusively of siliciclastic deposits, whereas the upper four formations are composed predominantly of carbonates. The Mungok Formation has been further subdivided into, in ascending order, the Garam, Baeiljae, Jeommal, and Dumok members (Kim and Choi, 2000b). A total of 19 trilobite zones are established in the Yeongwol Group (Fig. 4) and the geologic age of the group can be bracketed within the Cambrian Series 2 (Cambrian Stage 4 or Stage 3) to Middle Ordovician (Darriwilian).

2.3 Mungyeong Group

The Mungyeong Group was proposed for the Cambrian–Ordovician strata of the Mungyeong-type

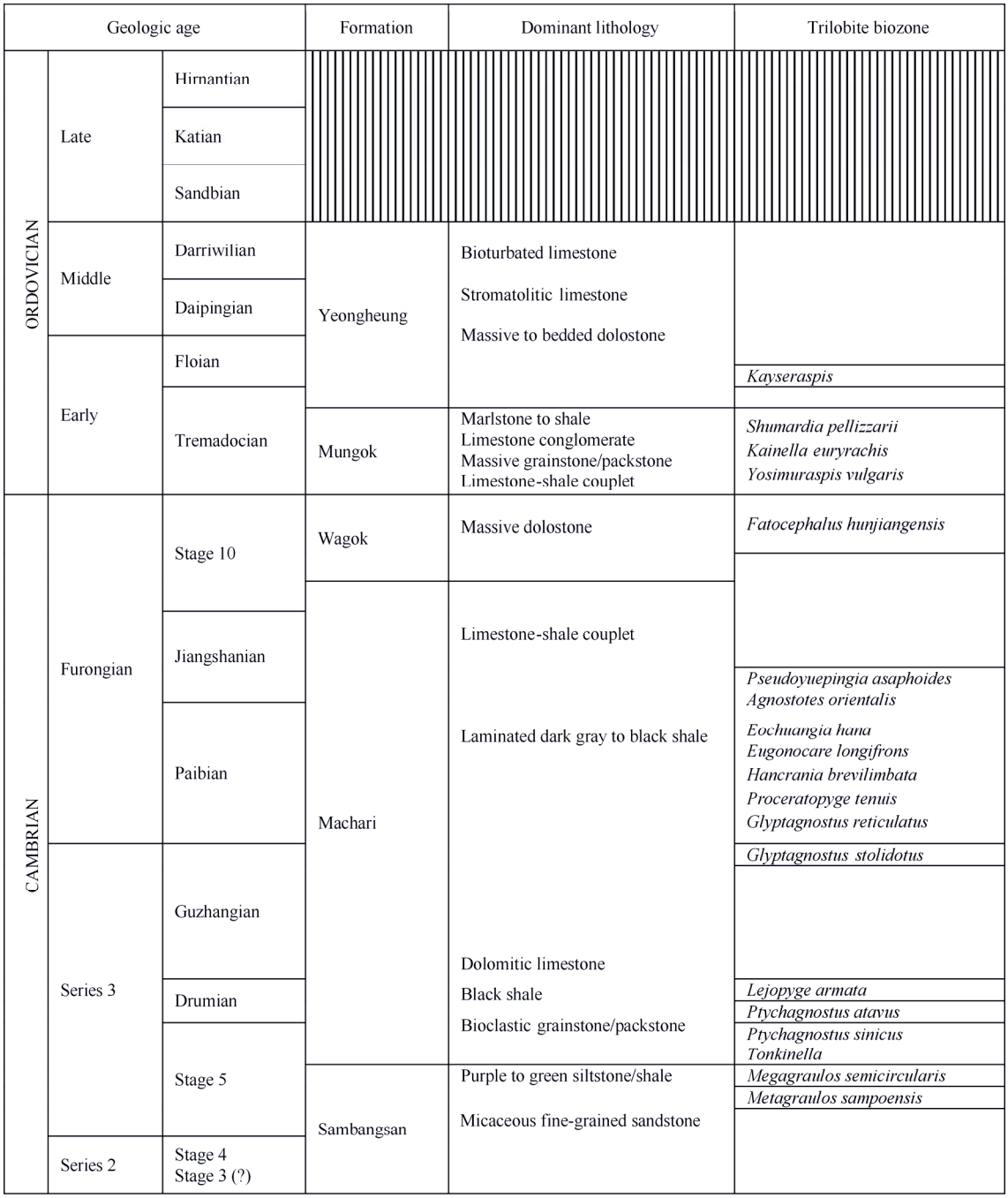

Fig. 4. Lithostratigraphic and biostratigraphic summary of the Yeongwol Group, Taebaeksan Basin, Korea.

Joseon Supergroup (Kobayashi, 1966) exposed in the Mungyeong area (Son, 1971; fig. 1). It occurs in the southernmost part of the Taebaeksan Basin, bounded to the east by the Seokhyeon thrust and to the west by the Sangnaeri thrust (Kobayashi et al., 1942). The Mungyeong Group has not been investigated in detail yet and is generally subdivided into the Gurangni Formation in the lower and undifferentiated carbonate formation in the upper (Um et al., 1977; Choi, 1998a; fig. 2). The Mungyeong Group is overlain by the Upper Ordovician Ongnyeobong Formation (Cho et al., 2014).

3 Fossil Localities: Sections and Points

As compiled in Figures 3 and 4, twenty-two and nineteen trilobite biozones have been newly established or confirmed in the Taebaek Group and in the Yeongwol Group, respectively. During the last two decades, a fair number of new biozones were established in the Taebaek and Yeongwol groups: the Taebaek Group includes the

Crepicephalina, *Amphoton*, *Jiulongshania*, *Liostracina simesi*, *Fenghuangella laevis*, *Asioptychaspis subglobosa, Quadraticephalus, Eosaukia*, *Pseudokoldinioidia*, *Richardsonella*, *Kayseraspis*, and *Dolerobasilicus* zones, whereas the Yeongwol Group comprises the *Ptychagnostus sinicus*, *Ptychagnostus atavus*, *Lejopyge armata*, *Glyptagnostus stolidotus*, *Proceratopyge tenuis*, *Eugonocare longifrons*, *Agnostotes orientalis*, *Fatocephalus hunjiangensis*, *Kainella euryrachis*, *Shumardia pellizzarii*, and *Kayseraspis* zones.

The revised trilobite biostratigraphy of the Joseon Supergroup was made possible by locating a number of new fossil localities in the Taebaeksan Basin during the last quarter century. Some fossil localities, the Seokgaejae and Eodungol sections, occur along a long mountain trail, while others are represented by a short section or a point. Figures 5 and 6 summarize some basic information on the fossil localities employed in refining the trilobite biostratigraphy of the Taebaek and Yeongwol groups respectively, including the geographic coordinates, formations, biozones, and relevant references.

4 Biostratigraphy

Kobayashi (1933) was the first to introduce the biozones for the upper Cambrian strata in Korea, which include, from oldest to youngest, the *Chuangia*, *Kaolishania*, *Tsinania*, and *Eoorthis* zones. Kobayashi (1934b) also proposed three Lower Ordovician zones within the Dumugol and Makgol formations: namely, in ascending order, the *Asaphellus*, *Protopliomerops*, and *Clarkella* zones. Subsequent studies on the trilobite faunas of the Taebaeksan Basin (Kobayashi, 1935, 1960a, 1960b, 1961, 1962) formed the basis for establishing the Cambrian–Ordovician biostratigraphic zonation of the Taebaek and Yeongwol groups. The contrasting faunal contents of the Taebaek and Yeongwol groups resulted in two separate biostratigraphic schemes for the Cambrian–Ordovician successions of the Taebaeksan Basin (Kobayashi, 1966). Over 20 zones and fossiliferous horizons were recognized in the Taebaek Group, whereas eleven zones were established in the Yeongwol Group. However, most of these biozones were recognized by the occurrences of trilobite faunal assemblages, which were arranged in a chronological order, and therefore may not be regarded as formal biostratigraphic zones.

The biostratigraphic zonation suggested by Kobayashi (1966) was widely employed in Korea without criticism, until trilobites of the Taebaek and Yeongwol groups were re-examined extensively during the last quarter century

Section/point	Geographic coordinate	Formation	Biozone recognized	References
1 Seokgaejae	129°08'30" E, 37°04'05" N … 129°07'57" E, 37°04'57" N	Duwibong Jigunsan Makgol Dumugol Dongjeom Hwajeol Sesong Daegi Myobong Myeonsan	*Richardsonella* *Pseudoko ldinioidia* *Eosaukia* *Quadraticephalus* *Asioptycha spis* *Neodrepanura* *Jiulongshanji a* *Amphoton* *Crepicephalina*	Choi et al. (2004a) Kang and Choi (2007) Sohn and Choi (2007) Lee and Choi (2007, 2011) Park et al. (2013) Kihm et al. (2013)
2 Sagundari	129°01'03" E, 37°04'57" N	Hwajeol Sesong	*Quadraticephalus* *Asioptychaspis* *Kaolishania*	Sohn and Choi (2005, 2007) Park and Choi (2010, 2011, 2012) Park et al. (2012) Park and Kihm (2015)
3 Gumunso	129°02'37" E, 37°05'25" N	Dumugol	*Kayseraspis* *Protopliomerops* *Asaphellus*	Kim et al. (1991)
4 Napalgogae	129°02'43" E, 37°05'55" N	Jigunsan	*Dolerobasilicus*	Lee and Choi (1992) Choi et al. (2001)
5 Gadeoksan	128°57'24" E, 37°16'21" N	Sesong Daegi	*Jiulongshania*	Park et al. (2009)
6 Jikdong	128°46' 31" E, 37°10' 31" N	Sesong Daegi	*Chuangia* *Prochuangia mansuyi* *Fenghuangella laevis* *Liostracina simesi* *Neodrepanura* *Jiulongshania*	Park and Choi (2011) Park et al. (2008, 2013)

Fig. 5. Abridged information on the fossil localities of the Taebaek Group, Taebaeksan Basin, Korea.

Section/point	Geographic coordinate	Formation	Biozone recognized	References
1 Eodungol	128°26'43"E, 37°19'47"N 128°26'31"E, 37°19'41"N	Machari Sambangsan	*Glyptagnostus reticulatus* *Lejopyge armata* *Tonkinella* *Megagraulos semicircularis* *Metagraulos sampoensis*	Lee and Choi (1994) Choi et al. (1999) Hong et al. (2003b)
2 Gonggiri	128°26' 23"E, 37°18'54"N	Machari	*Pseudoyuepingia asaphoides* *Agnostotes orientalis* *Eochuangia hana*	Hong et al. (2003a) Choi et al. (2004b, 2008) Choi and Kim (2006)
3 Gamaesil	128°26'01"E, 37°18'24"N	Machari	*Pseudoyuepingia asaphoides*	Lee and Choi (1996)
4 Machari	128°27'56"E, 37°15'38"N	Machari	*Glyptagnostus reticulatus*	Lee and Choi (1994, 1995)
5 Deogu	128°27'55"E, 37°14'19"N	Machari	*Eugonocare longifrons* *Hancrania brevilimbata* *Proceratopyge tenuis* *Glyptagnostus reticulatus* *Glyptagnostus stolidotus*	Lee and Choi (1994, 1995) Choi and Lee (1995)
6 Bundeokjae	128°27'51"E, 37°13'41"N	Machari	*Eugonocare longifrons* *Hancrania brevilimbata* *Proceratopyge tenuis* *Glyptagnostus reticulatus*	Lee and Choi (1994, 1995)
7 Deoksang	128°22'40" E, 37°16'50" N	Machari Sambangsan	*Glyptagnostus reticulatus* *Glyptagnostus stolidotus* *Lejopyge armata* *Ptychagnostus atavus* *Ptychagnostus sinicus* *Tonkinella*	Hong (2014) Hong and Choi (2015)
8 Garam	128°25'55" E, 37°17'40" N	Mungok Wagok	*Shumardia pellizzarii* *Yosimuraspis vulgaris*	Kim and Choi (2000a, b)
9 Seonghwang-dong	128°26'09" E, 37°16'58" N	Mungok	*Kainella euryrachis*	Kim and Choi (1999)
10 Jeommal	128°23'47" E, 37°13'00" N	Mungok	*Kainella euryrachis*	Kim and Choi (1995)
11 Baeiljae	128°23'33" E, 37°13'26" N	Mungok Wagok	*Shumardia pellizzarii* *Yosimuraspis vulgaris*	Kim and Choi (2000a, b)
12 Dumok	128°25'51" E, 37°12'51" N	Yeongheung Mungok Wagok	*Shumardia pellizzarii* *Yosimuraspis vulgaris*	Kim and Choi (2000a, b)
13 Eosangcheon	128°21'55" E, 37°06'55" N	Wagok (?)	*Fatocephalus hunjiangensis*	Sohn and Choi (2002)
14 Maepo	128°15'30" E, 37°03'30" N	Yeongheung (?)	*Kayseraspis*	Choi (1998b)

Fig. 6. Abridged information on the fossil localities of the Yeongwol Group, Taebaeksan Basin, Korea.

(see Figs. 5 and 6). The revised trilobite biostratigraphy of the Taebaek and Yeongwol groups provides a more reliable correlation with the Cambrian–Ordovician biozones established elsewhere (cf. Geyer and Shergold, 2000; Peng et al., 2012b). On the other hand, the lower Paleozoic trilobites of the Mungyeong Group have not yet been re-evaluated, and hence the biozones of the Mungyeong Group will be briefly summarized based on the information provided by Kobayashi (1961).

4.1 Trilobite biozones of the Taebaek Group

Trilobites have been reported from all but the lowermost Jangsan and Myeonsan formations of the Taebaek Group (Kobayashi, 1966). The trilobite biozones of the Taebaek Group have been intensively re-investigated during the last decade, except for the Myobong Formation. The biozones of the Myobong Formation are summarized in Kobayashi (1966). The trilobite faunal assemblages of the Taebaek Group allow the establishment of 22 biozones: in ascending order, *Redlichia*, *Elrathia*, *Mapania* (?), *Bailiella*, *Crepicephalina*, *Amphoton*, *Jiulongshania*, *Neodrepanura*,

Liostracina simesi, *Fenghuangella laevis*, *Prochuangia mansuyi*, *Chuangia*, *Kaolishania*, *Asioptychaspis subglobosa*, *Quadraticephalus*, *Eosaukia*, *Pseudokoldinioidia*, *Richardsonella*, *Asaphellus*, *Protopliomerops*, *Kayseraspis*, and *Dolerobasilicus* zones (Fig. 3).

4.1.1 *Redlichia* Zone

The *Redlichia* Zone of the Myobong Formation is the lowermost biozone of the Taebaek Group and was recognized on the basis of a sole occurrence of *Redlichia saitoi* Lu, 1950 at Seokgaejae area (Kobayashi, 1960b). *Redlichia saitoi* was originally reported to occur in the Pyongnam Basin of North Korea (Saito, 1934) and Hubei Province, China (Lu, 1950).

4.1.2 *Elrathia* Zone

The *Elrathia* Zone of the Myobong Formation has been known to yield the trilobite *Elrathia taikiensis* Kobayashi, 1935 and the brachiopod *Nisusia cooperi* Kobayashi, 1935 (Kobayashi, 1966).

4.1.3 *Mapania* (?) Zone

Kobayashi (1935) proposed the *Mapania* Zone upon the observation of *Mapania beihoensis* Kobayashi, 1935 from Taebaek. However, the occurrence of *Mapania* from the Myobong Formation was doubted by Zhang (1988), because *Mapania* was known to be a characteristic element of the much younger *Amphoton* Zone of North China.

4.1.4 *Bailiella* Zone

The *Bailiella* Zone was established on the occurrence of *Bailiella angusta* Kobayashi, 1960b. It was originally reported to occur in the lowermost part of the Daegi Formation (Kobayashi, 1960b), but later, without any explanation, was put into the uppermost zone of the Myobong Formation (Kobayashi, 1966).

4.1.5 *Crepicephalina* Zone

The *Crepicephalina* Zone occurs in the lower 30-m-thick interval of the Daegi Formation in the Seokgaejae section (Kang and Choi, 2007). It comprises 10 trilobite species including *Ammagnostus laiwuensis* (Lorenz, 1906), *Dorypyge richthofeni* Dames, 1883, *Anomocarella temenus* (Walcott, 1905), a ptychopariid species, *Changqingia deprati* (Kobayashi, 1935), *Crepicephalina damia* (Walcott, 1905), *Proasaphiscus* sp., *Manchuriella macar* (Walcott, 1911), *Ignotogregatus* sp. cf. *I. manhole* Zhang and Jell, 1987, and *Metanomocarella tumida* (Resser and Endo, 1937). The former two species range upwards into the overlying *Amphoton* Zone, while the remaining eight species are confined to this zone.

4.1.6 *Amphoton* Zone

The *Amphoton* Zone occupies an interval of 70–90 m above the base of the Daegi Formation in the Seokgaejae section, and is defined by the occurrence of *Amphoton deois* (Walcott, 1905). This zone yields two additional species, *Ammagnostus laiwuensis* and *Dorypyge richthofeni*. While the latter two species range from the *Crepicephalina* Zone into this zone, *Amphoton deois* is restricted to the *Amphoton* Zone. *Dorypyge richthofeni* is particularly abundant, comprising about 80% of the fauna in abundance.

4.1.7 *Jiulongshania* Zone

The *Jiulongshania* Zone was originally proposed as the *Cyclolorenzella* Zone based on *Cyclolorenzella rotundata* (Resser and Endo, 1937) which occurs in the uppermost 5-m-thick interval of the Daegi Formation in the Seokgaejae section (Kang and Choi, 2007). However, Park et al. (2008) demonstrated that *C. rotundata* is morphologically distinct from the type species of *Cyclolorenzella* and belongs to *Jiulongshania* Park et al., 2008, and subsequently the *Cyclolorenzella* Zone has been renamed as the *Jiulongshania* Zone. The *Jiulongshania* Zone extends upwards into the lowermost 20-m-thick interval of the Sesong Formation (Park et al., 2013).

In addition to *J. rotundata*, the *Jiulongshania* Zone of the Daegi Formation comprises *Ammagnostus* sp., *Jiulongshania* sp., *Blackwelderia* sp., *Teinistion*? sp., and *Palaeadotes*? sp. (Kang and Choi, 2007). The *Jiulongshania* Zone of the Sesong Formation yields a comparatively diverse trilobite assemblage (Park et al., 2013) including *Jiulongshania longispina* (Wittke and Zhu in Zhu and Wittke, 1989), *J. regularis* (Walcott, 1906), *Bergeronites ketteleri* (Monke, 1903), *Teinistion lansi* Monke, 1903, *Teinistion* sp., *Blackwelderia* spp., *Liostracina* sp. cf. *L. bilimbata* Zhang in Qiu et al., 1983, *Stephanocare richthofeni* Monke, 1903, *Hebeia* sp., *Monkaspis* sp., and two damesellid species.

4.1.8 *Neodrepanura* Zone

Kobayashi (1966) reported 15 trilobite species along with some brachiopods and gastropods from the "*Drepanura*" Zone of the Sesong Formation and correlated it with the "*Drepanura*" Zone of North China. The "*Drepanura*" Zone was renamed as the *Neodrepanura* Zone by Park and Choi (2011), as a new name *Neodrepanura* was proposed to replace *Drepanura* Bergeron, 1899 (Özdikmen, 2006). The *Neodrepanura* Zone has been recognized in the two horizons of the Sesong Formation at the Jikdong section and contains four species: i.e., *Neodrepanura* sp., *Liostracina* sp., *Teinistion* sp., and *Huzhuia* sp. (Park and Choi, 2011). These four

species are restricted in occurrence to this zone.

4.1.9 *Liostracina simesi* Zone

The *Liostracina simesi* Zone was established on the observation of *Liostracina simesi* Jago and Cooper, 2005 and *Parachangshania rectangularis* Park and Choi, 2011 from a relatively narrow interval (ca. 50-cm-thick) of the Jikdong section (Park and Choi, 2011).

4.1.10 *Fenghuangella laevis* Zone

The *Fenghuangella laevis* Zone was established on the first appearance of *Placosema bigranulosum* Peng et al., 2004a and *Fenghuangella laevis* Park and Choi, 2011 in the Jikdong section, and comprises four additional trilobite taxa including *Baikadamaspis jikdongensis* Park and Choi, 2011, *Baikadamaspis* sp., *Parachangshania monkei* (Kobayashi, 1935), and a ceratopygid species (Park and Choi, 2011). The *Fenghuangella laevis* Zone occupies an interval of 27.5–31.5 m above the base of the Sesong Formation in the Jikdong section. Two species, *Placosema bigranulosum* and *Baikadamaspis* sp., are restricted to this zone, while the remaining four species extend their stratigraphic ranges upwards into the *Prochuangia mansuyi* Zone.

4.1.11 *Prochuangia mansuyi* Zone

The *Prochuangia mansuyi* Zone was originally known to occupy the lowermost part of the Hwajeol Formation (Kobayashi, 1966), but was transferred to the upper part of the Sesong Formation based on the redefinition of lithostratigraphy of the Taebaek Group by Sohn and Choi (2005b). Subsequently, Park and Choi (2011) recognized the *Prochuangia mansuyi* Zone from the Sesong Formation at the Jikdong section based on the documentation of the FAD of *Prochuangia mansuyi* Kobayashi, 1935. The *Prochuangia mansuyi* Zone contains eight polymerid trilobite species, *Fenghuangella laevis*, *Parachangshania monkei*, *Baikadamaspis jikdongensis*, a ceratopygid species, *Prochuangia mansuyi*, *Huzhuia* sp., *Alataspis sesongensis* Park and Choi, 2011, and *Maladioides coreanicus* Kobayashi, 1935. The first four species first appear in the *Fenghuangella laevis* Zone and their stratigraphic ranges extend into the *Prochuangia mansuyi* Zone, while the latter four species are confined to this zone.

4.1.12 *Chuangia* Zone

Kobayashi (1966) listed 10 trilobite species from the *Chuangia* Zone and correlated it with the Changshanian Stage of North China. A subsequent study (Park and Choi, 2011) rather vaguely recognized the *Chuangia* Zone based on the recovery of two poorly preserved trilobite species from the Jikdong section: *Chuangia* sp. and a ceratopygid species.

4.1.13 *Kaolishania* Zone

The *Kaolishania* Zone was originally established by Kobayashi (1935) and has been known to comprise a relatively diverse faunal assemblage including 15 trilobite and five brachiopod species (Kobayashi, 1966). Park et al. (2012) relocated the *Kaolishania* Zone in the upper part of the Sesong Formation at the Sagundari section, where 13 polymerid species were documented: i.e., *Shirakiella elongata* Kobayashi, 1935, *Shirakiella* sp., *Taishania*? sp., *Acanthometopus* sp., *Pagodia* sp. cf. *P. spina* Qian, 1994, *Kaolishania granulosa* Kobayashi, 1933, *Gumunsoia triangularis* Park et al., 2012, *Gumunsoia* sp., *Elaphraella microforma* Lu and Qian, 1983, *E. nodus* (Qian, 1994), *E.*? *taebaeksanensis Park and Choi, 2012, Lingyuanaspis* sp., and a kaolishaniid species.

4.1.14 *Asioptychaspis subglobosa* Zone

The *Asioptychaspis subglobosa* Zone was recognized in a relatively narrow interval (ca. 1-m-thick) of the lowermost part of the Hwajeol Formation in the Sagundari section (Sohn and Choi, 2007; Park and Choi, 2010; Park and Kihm, 2015). This zone yields 17 trilobite species: i.e., *Asioptychaspis subglobosa* (Sun, 1924), *Akoldinioidia latus* Park and Kihm, 2015, ?*Saukia aojii* Kobayashi, 1933, *Wuhuia belus* (Walcott, 1905), *Gumunsoia* sp., *Koldinioidia choii* Park and Kihm, 2015, *Caznaia coreaensis* Park and Kihm, 2015, *Parakoldinioidia* sp., *Pseudokoldinioidia* sp. cf. *P. granulosa* Endo, 1944, *Guangxiaspis* sp., *?Mansuyia* sp., *Baikadamaspis* sp., *Haniwa quadrata* Kobayashi, 1933, a ptychaspidid species, *Pseudagnostus planulatus* (Raymond, 1924), and *Tsinania canens* (Walcott, 1905). The former 13 species are restricted in occurrence to this zone, whilst *P. planulatus*, *T. canens*, *H. quadrata*, and a ptychaspidid species extend their stratigraphic ranges into the succeeding *Quadraticephalus* Zone.

4.1.15 *Quadraticephalus* Zone

The *Quadraticephalus* Zone was recognized by the first appearance of *Lophosaukia orientalis* (Kobayashi, 1933), *Quadraticephalus elongatus* Kobayashi, 1935, and *Hamashania pulchera* (Kobayashi, 1942a) from the lower part of the Hwajeol Formation in the Seokgaejae and Sagundari sections (Sohn and Choi, 2007). In addition, the *Quadraticephalus* Zone comprises *Haniwa quadrata*, ptychaspidid gen. et sp. indet., *Tsinania canens*, *Pseudagnostus planulatus*, *Micragnostus* sp., *Lophosaukia* sp., *Hamashania* sp. cf. *H. busiris* (Walcott, 1905), *Koldinioidia* sp., and *Changia* sp. (Sohn and Choi, 2005a,

2007; Kihm et al., 2013). The first four species first appear in the underlying *Asioptychaspis subglobosa* Zone and their stratigraphic ranges extend into the *Quadraticephalus* Zone, while the remaining eight species are restricted to this zone.

4.1.16 *Eosaukia* Zone

The *Eosaukia* Zone was proposed for the interval yielding an upper Furongian trilobite faunal assemblage from the upper part of the Hwajeol Formation to the lowermost part of the Dongjeom Formation in the Seokgaejae section (Lee and Choi, 2011). The lower boundary of the *Eosaukia* Zone is indeterminate due to rare occurrences of trilobites from the interval below, and is presumed to be underlain by the *Quadraticephalus* Zone. This fauna is dominated by dikelocephalid trilobites including *Eosaukia micropora* (Qian, 1985), *E. bella* (Walcott, 1906), *E. acuta* (Kuo and Duan in Kuo et al., 1982), *Mictosaukia* sp. cf. *M. globosa* (Robison and Pantoja-Alor, 1968), and *Taebaeksaukia spinata* Lee and Choi, 2011, but also has been known to include species of *Micragnostus*, *Koldinioidia*, *Quadraticephalus*, and *Pagodia* (Choi et al., 2003).

4.1.17 *Pseudokoldinioidia* Zone

The *Pseudokoldinioidia* Zone is established for an uppermost Cambrian trilobite faunal assemblage from the lower part of the Dongjeom Formation in the Seokgaejae section (Lee and Choi, 2007) and is characterized by low species diversity composed of six trilobite taxa: i.e., *Micragnostus chiushuensis* (Kobayashi, 1931), *Koldinioidia typicalis* Kobayashi, 1931, a leiostegiid species, *Pseudokoldinioidia perpetis* (Zhou and Zhang, 1985), *Onychopyge borealis* Zhou and Zhang, 1978, and a pilekiid species.

4.1.18 *Richardsonella* Zone

The *Richardsonella* Zone is named for the kainellid-dominated fauna from the lower part of the Dongjeom Formation in the Seokgaejae section (Lee and Choi, 2007); it contains species of *Micragnostus*, *Pseudorhaptagnostus*, *Richardsonella*, *Yosimuraspis*, and *Platypeltoides* (Choi et al., 2004a). The trilobite fauna of the *Richardsonella* Zone has not yet been studied in detail.

4.1.19 *Asaphellus* Zone

The *Asaphellus* Zone was originally erected by Kobayashi (1934b). This zone is recognized by the common occurrence of *Asaphellus* from the lower half of the Dumugol Formation at the Gumunso section and comprises *Asaphellus tomkolensis* Kobayashi, 1934b, *A. coreanicus* Kobayashi, 1934b, and *Hystricurus* sp. (Kim et al., 1991).

4.1.20 *Protopliomerops* Zone

The *Protopliomerops* Zone was also established by Kobayashi (1934b), who listed the occurrence of 14 trilobite species (Kobayashi, 1966). However, the *Protopliomerops* Zone has not been well defined due to the sporadic occurrence of the trilobites from the Dumugol Formation (Kim et al., 1991). Kim et al. (1991) documented *Apatokephalus* sp. and *Hystricurus* sp. from the *Protopliomerops* Zone of the Gumunso section.

4.1.21 *Kayseraspis* Zone

The *Kayseraspis* Zone was recognized on the occurrence of *Kayseraspis laticauda* (Kobayashi, 1934b) and *Asaphopsoides nakamurai* (Kobayashi, 1936) from the upper part of the Dumugol Formation in the Gumunso section (Kim et al., 1991) and was assigned to the Arenigian (=Floian) in age.

4.1.22 *Dolerobasilicus* Zone

Trilobites of the Jigunsan Formation were first studied by Kobayashi (1934a), who described a total of 17 species. Lee et al. (1980) added five new species to the list. However, Lee and Choi (1992) demonstrated that the Jigunsan trilobite fauna comprises only four valid species: *Dolerobasilicus yokusensis* (Kobayashi, 1934a), *Basiliella kawasakii* Kobayashi, 1934a, *B. typicalis* (Kobayashi, 1934a), and *Ptychopyge dongjeomensis* Lee and Cheong in Lee et al., 1980. Choi et al. (2001) proposed the *Dolerobasilicus* Zone for the fossiliferous interval of the Jigunsan Formation.

4.2 Trilobite biozones of the Yeongwol Group

The Yeongwol Group have been intensively studied during the last two decades (Fig. 6), which resulted in the recognition of 19 trilobite biozones within the group: in ascending order, *Metagraulos sampoensis*, *Megagraulos semicircularis*, *Tonkinella*, *Ptychagnostus sinicus*, *Ptychagnostus atavus*, *Lejopyge armata*, *Glyptagnostus stolidotus*, *Glyptagnostus reticulatus*, *Proceratopyge tenuis*, *Hancrania brevilimbata*, *Eugonocare longifrons*, *Eochuangia hana*, *Agnostotes orientalis*, *Pseudoyuepingia asaphoides*, *Fatocephalus hunjiangensis*, *Yosimuraspis vulgaris*, *Kainella euryrachis*, *Shumardia pellizzarii*, and *Kayseraspis* zones (Fig. 4).

4.2.1 *Metagraulos sampoensis* Zone

The *Metagraulos sampoensis* Zone is recognized on the basis of a sole occurrence of *Metagraulos sampoensis* Kobayashi, 1961 in the upper part of the Sambangsan

Formation exposed in the Eodungol section (Choi et al., 1999).

4.2.2 *Megagraulos semicircularis* Zone

The *Megagraulos semicircularis* Zone is defined by the occurrence of *Megagraulos semicircularis* Kobayashi, 1961 in the upper part of the Sambangsan Formation in the Eodungol section. *Metagraulos sampoensis* is also observed in the lowermost horizon of the zone (Choi et al., 1999). However, Yuan et al. (2012) suggested that *Megagraulos semicircularis* may be better accommodated by *Plesiagraulos* Chang, 1963.

4.2.3 *Tonkinella* Zone

The *Tonkinella* Zone was established by Kobayashi (1962) based on the prolific occurrence of *Tonkinella*, *Olenoides*, *Kootenia*, and *Peronopsis* in the Machari Formation. This zone has been recognized at the lowermost part of the Machari Formation in the Eodungol section (Lee, 1995) and in the Deoksang section (Hong, 2014), but has not yet been studied in detail.

4.2.4 *Ptychagnostus sinicus* Zone

The *Ptychagnostus sinicus* Zone is recognized by the occurrence of *Ptychagnostus sinicus* Lu, 1957 at an interval of 6.0–6.9 m above the base of the Machari Formation at the Deoksang section (Hong and Choi, 2015). *Peronopsis taitzuhoensis* Lu, 1957 is restricted to the lowermost horizon of the zone.

4.2.5 *Ptychagnostus atavus* Zone

The *Ptychagnostus atavus* Zone covers an interval of 7.0–7.5 m above the base of the Machari Formation at the Deoksang section (Hong and Choi, 2015). Aside from *Ptychagnostus atavus* (Tullberg, 1880), *Yakutiana ovale* (Yang, 1982) occurs abundantly throughout the zone, while *Hypagnostus parvifrons* (Linnarsson, 1869) and *Diplagnostus planicauda* (Angelin, 1851) are confined to the uppermost horizon of the zone.

4.2.6 *Lejopyge armata* Zone

The *Lejopyge armata* Zone is recognized at ca. 30 m above the base of the Machari Formation in the Eodungol section (Hong et al., 2003a) and 7.6–8.8 m above the base of the Machari Formation in the Deoksang section (Hong, 2014). In the Eodungol section, seven trilobite species are known: i.e., *Lejopyge armata* (Linnarsson, 1869), *Lisogoragnostus coreanicus* (Hong et al., 2003a), an agnostid species, an ammagnostid species, a clavagnostid species, *Cyclolorenzella* sp., and *Eoshengia*? sp. In the Deoksang section, *Diplagnostus planicauda*, *Yakutiana ovale*, and *Hypagnostus parvifrons*, *Kormagnostus minutus* (Schrank, 1975), and *Nahannagnostus nganasanicus* (Rozova, 1964) are present.

4.2.7 *Glyptagnostus stolidotus* Zone

The *Glyptagnostus stolidotus* Zone of the Machari Formation has been documented in the Deogu and Deoksang sections (Lee and Choi, 1994; Choi and Lee, 1995; Hong, 2014). This zone yields only two agnostoid species, *G. stolidotus* Öpik, 1961 and *Pseudagnostus josepha* (Hall, 1863).

4.2.8 *Glyptagnostus reticulatus* Zone

The *Glyptagnostus reticulatus* Zone has been documented from the Machari Formation of the Bundeokjae, Deogu, Machari, Eodungol, and Deoksang sections (Lee and Choi, 1994, 1997; Choi and Lee, 1995; Hong, 2014). It has been known to yield six trilobite species: i.e., *Glyptagnostus reticulatus* (Angelin, 1851), *Aspidagnotus stictus* Öpik, 1967, *Innitagnostus innitens* Öpik, 1967, *Peratagnostus obsoletus* (Kobayashi, 1935), *Olenus asiaticus* Kobayashi, 1935, and *Proceratopyge* sp. cf. *P. tenuis* (Kobayashi, 1962).

4.2.9 *Proceratopyge tenuis* Zone

The *Proceratopyge tenuis* Zone was recognized in the Bundeokjae, Deogu, and Machari sections (Lee and Choi, 1995). It occupies a rather poorly fossiliferous interval between the *Glyptagnostus reticulatus* and *Hancrania brevilimbata* zones and comprises four trilobite species: *Peratagnostus obsoletus*, *Pseudagnostus josepha*, *Proceratopyge tenuis*, and *Erixanium* sp.

4.2.10 *Hancrania brevilimbata* Zone

The *Hancrania brevilimbata* Zone has been recognized in the Bundeokjae and Deogu sections (Lee and Choi, 1995) and yields seven species such as *Innitagnostus inexpectans* (Kobayashi, 1938), *Peratagnostus obsoletus*, *Lisogoragnostus minor* (Kobayashi, 1962), *Pseudagnostus josepha*, *Hancrania brevilimbata* Kobayashi, 1962, *Proceratopyge elongata* Lee and Choi, 1995, and *Stigmatoa coreanica* (Kobayashi, 1962).

4.2.11 *Eugonocare longifrons* Zone

The *Eugonocare longifrons* Zone has been documented in the Bundeokjae and Deogu sections (Lee and Choi, 1995) and is relatively diverse in comprising nine trilobite species: viz., *Innitagnostus* sp., *Peratagnostus obsoletus*, *Lisogoragnostus minor*, *Pseudagnostus josepha*, *Kormagnostus* sp., *Erixanium similis* (Kobayashi, 1962), *Eugonocare longifrons* (Kobayashi, 1962), *Proceratopyge praelonga* Lee and Choi, 1995, and *Irvingella typa* (Kobayashi, 1962).

4.2.12 *Eochuangia hana* Zone

The *Eochuangia hana* Zone is recognized from the Machari Formation of the Gonggiri section (Choi et al., 2004b, 2008). This zone comprises a very diverse faunal assemblage including 12 agnostoids and at least 12 polymerid trilobites: they are *Homagnostus obesus* (Belt, 1867), *H.*? *sulcatus* Choi et al., 2004b, *Micragnostus elongatus* (Chien, 1961), *M.* aff. *intermedius* (Palmer, 1968), *Kormagnostus inventus* (Shergold, 1982), *Pseudagnostus josepha*, *P. securiger* (Lake, 1906), *Ivshinagnostus hunanensis* (Peng, 1992), *I. alatus* Choi et al., 2004b, *I. quadratus* Choi et al., 2004b, *Pseudorhaptagnostus tumidus* (Sun, 1989), *Nahannagnostus pratti* Choi et al., 2004b, *Irvingella megalops* (Kobayashi, 1962), *I. convexa* (Kobayashi, 1935), *Proceratopyge promisca* Choi et al., 2008, *Pseudeugonocare bispinatum* (Kobayashi, 1962), *Macharia pengi* Choi et al., 2008, *Joshuaspis parvus* Choi et al., 2008, *Dikelocephalites flabelliformis* Sun, 1935, *Haniwoides longus* Kobayashi, 1935, *Eochuangia hana* Kobayashi, 1935, *Changshania equalis* Sun, 1935, *Metachangshania brachypyga* Choi et al., 2008, and *Chuangia* spp.

4.2.13 *Agnostotes orientalis* Zone

The *Agnostotes orientalis* Zone of the Machari Formation is documented in the Gonggiri section (Choi et al., 2004b, 2008). This zone also yields a relatively diverse faunal assemblage with 12 agnostoids and six polymerid trilobites: i.e., *Kormagnostus inventus*, *Micragnostus* aff. *intermedius*, *Pseudagnostus josepha*, *Ivshinagnostus quadratus*, *Pseudorhaptagnostus tumidus*, *Nahannagnostus pratti*, *Agnostotes orientalis* (Kobayashi, 1935), *Yongwolagnostus dubius* Choi et al., 2004b, *Y. stenorhachis* Choi et al., 2004b, *Pseudagnostus medius* Choi et al., 2004b, *P.*? *dividuus* Choi et al., 2004b, *Ammagnostus serus* Choi et al., 2004b, *Proceratopyge promisca, Pseudoeugonocare bispinatum, Haniwoides longus, Irvingella coreanica* Hong et al., 2003b*, I. major* Ulrich and Resser in Walcott, 1924*,* and *Chuangia* spp.

4.2.14 *Pseudoyuepingia asaphoides* Zone

The *Pseudoyuepingia asaphoides* Zone has been recognized in the Gonggiri and Gamaesil sections (Lee and Choi, 1996; Choi et al., 2004b, 2008). It comprises seven agnostoids including *Peratagnostus orientalis* (Lazarenko, 1966), *Lisogoragnostus minor*, *Pseudorhaptagnostus urceus* Choi et al., 2004b, *Pseudagnostus josepha*, *Pseudagnostus* sp., *Micragnostus hisakoshii* (Kobayashi, 1962), *M*. aff. *intermedius*, and *Acmarhachis typicalis* (Resser, 1938). The polymerid trilobites documented are *Pseudoyuepingia asaphoides* (Kobayashi, 1962), *Proceratopyge rectispinata* (Troedsson, 1937)*, Metachangshania* sp.*, Jingxiania* sp. cf. *J. beigongliensis* Chien in Lu et al., 1974*, Wuhuia* sp.*,* and an olenid species.

4.2.15 *Fatocephalus hunjiangensis* Zone

The *Fatocephalus hunjiangensis* Zone is recognized in Eosangcheon in the southwestern part of Yeongwol (Sohn and Choi, 2002). However the stratigraphic position of this zone is indeterminate, albeit it is provisionally included in the Wagok Formation (Fig. 4). This zone comprises seven trilobite species including *Micragnostus* aff. *elongatus* (Chien, 1961), *Micragnostus* sp., *Pseudorhaptagnostus* (*Machairagnostus*) *kentauensis* (Ergaliev, 1980), *Fatocephalus hunjiangensis* Duan and An in Kuo et al., 1982, *Koldinioidia longa* Lu and Lin, 1984, *Hysterolenus* sp., and *Amzasskiella*? sp.

4.2.16 *Yosimuraspis vulgaris* Zone

The *Yosimuraspis vulgaris* Zone occupies the lowermost Garam Member of the Mungok Formation and was recognized in the Garam and Baeiljae sections (Kim and Choi, 2000a, b). It includes *Yosimuraspis vulgaris* Kobayashi, 1960a, as the most abundant species plus *Jujuyaspis sinensis* Zhou in Chen et al., 1980*, Elkanaspis jilinensis* Qian in Chen et al., 1985*,* and a pilekid species (Kim and Choi, 2000a).

4.2.17 *Kainella euryrachis* Zone

The *Kainella euryrachis* Zone has been recognized in the lowermost part of the Jeommal Member of the Mungok Formation at the Jeommal and Seonghwangdong sections and yields *Kainella euryrachis* Kobayashi, 1953, *Leiostegium* sp., and an agnostoid species (Kim and Choi, 1995, 1999, 2000b).

4.2.18 *Shumardia pellizzarii* Zone

The *Shumardia pellizzarii* Zone occurs in a relatively long stratigraphic interval within the Dumok Member of the Mungok Formation at the Garam, Baeiljae and Dumok sections, and yields a fairly diverse trilobite assemblage including *Trilobagnostus coreanicus* (Kobayashi, 1960a), *Shumardia pellizzarii* Kobayashi, 1934b, *Apatokephalus hyotan* Kobayashi, 1953, *Hystricurus* sp. cf. *H. megalops* Kobayashi, 1934b, *Hystricurus* sp., *Asaphellus* spp., *Dikelokephalina asiatica* Kobayashi, 1934b, *Koraipsis spinus* Kobayashi, 1934b, *Hukasawaia cylindrica* Kobayashi, 1953, two pliomerid species, and an asaphid species (Choi et al., 1994; Kim and Choi, 2000b).

4.2.19 *Kayseraspis* Zone

The *Kayseraspis* Zone has been established in Maepo

and contains trilobites, gastropods, and ostracodes (Choi, 1998b). Trilobites include *Asaphellus*? sp., *Kayseraspis* sp. cf. *K. laticauda*, *Asaphopsoides maepoensis* Choi, 1998b, and an asaphid species. However, the lithostratigraphic position of this zone is indeterminate, although it is included in the Yeongheung Formation with reservation (Fig. 4).

4.3 Trilobite biozones of the Mungyeong Group

4.3.1 *Redlichia* Zone

The *Redlichia* Zone of the Mungyeong Group was recognized in the Gurangni Formation upon the exclusive occurrence of *Redlichia nobilis* Walcott, 1905 (Kobayashi, 1961).

4.3.2 *Palaeolenus* Zone

The *Palaeolenus* Zone was recognized at the horizon of about 10 m above the base of the Maseong Formation and has been known to yield *Palaeolenus aotii* Kobayashi, 1961 and *Redlichia* cf. *cylindrica* Chang, 1953 (Kobayashi, 1961).

4.3.3 *Ptychoparia-Dawsonia* Zone

The *Ptychoparia-Dawsonia* Zone was established within the Maseong Formation (Kobayashi, 1961) and has been known to yield *Ptychoparia* aff. *impar* Walcott, 1905 and *Dawsonia bunkeiensis* (Kobayashi, 1943).

4.3.4 *Kootenia* Zone

The *Kootenia* Zone was also recognized within the Maseong Formation (Kobayashi, 1961) and comprises *Kootenia amanoi* Kobayashi, 1961, *Mungyongia tulipiformis* Kobayashi, 1961, and *Amphoton spirula* Kobayashi, 1942b.

5 Correlation and Discussion

As described in the preceding section, the contrasting trilobite faunal assemblages of the Taebaek and Yeongwol groups led to two separate Cambrian–Ordovician biostratigraphic schemes for the Taebaeksan Basin, Korea (Figs. 3 and 4). The contrasting faunal contents between the two groups were more pronounced in the Cambrian than in the Ordovician, which has been attributed to the shift in the paleoenvironmental settings of the Taebaeksan Basin in the early Paleozoic (Choi and Kim, 2006; Choi, 2009). In the Cambrian, the Taebaek Group formed in a shallow marine inner-shelf environment, whereas the Yeongwol Group was deposited in a more offshore deeper-water setting. In the Ordovician, the Taebaeksan Basin was transformed into a low-relief carbonate platform setting scattered with shoals, lagoons, and tidal flats (Choi et al., 2001). The early Paleozoic paleogeographic reconstruction employing the trilobite faunal assemblages and detrital zircon age spectra of the Taebaeksan Basin (Choi, 2014) shows that the Sino-Korean Craton occupied a marginal part of east Gondwana and that the Taebaeksan Basin was a part of an epeiric sea located close to Australia and South China Craton. The epeiric sea was considered the site for deposition of the lower Paleozoic successions which are now widely exposed on the Sino-Korean Craton. Therefore, it seems practical to correlate the early Paleozoic biostratigraphic zonation of the Taebaeksan Basin with those of North China, South China, and Australia (see Figs. 7 and 8).

5.1 Cambrian Stage 4

The *Redlichia* Zone of the Taebaek and Mungyeong groups represents the oldest biozone established in the Taebaeksan Basin. The *Redlichia* Zone can be broadly correlated with the *Redlichia* Zone (Duyunian Stage) of North China (Zhou and Zhen, 2008) and the *Xystridura-Redlichia* Zone (Ordian Stage) of Australia (Kruse et al., 2009).

5.2 Cambrian Stage 5

The Cambrian Stage 5 biozones of the Taebaek Group are at present poorly known and thus the correlation given in Figure 7 is provisional and inconclusive, while the Cambrian Stage 5 biozones of the Yeongwol Group are comparatively well understood.

The *Metagraulos sampoensis* Zone is the oldest biozone recognized in the Yeongwol Group. The genus *Metagraulos* has so far been known from the *Metagraulos* Zone (Hsuchuangian Stage) of North China (Zhang and Jell, 1987; Yuan et al., 2012), to which the *Metagraulos sampoensis* Zone can be correlated. On the other hand, it is difficult to correlate the *Megagraulos semicircularis* Zone with the biozones of North China, because the *Megagraulos* Zone in North China was reported in the much younger Wangcunian Stage of the Changhia Formation (Zhang and Jell, 1987; Yuan et al., 2012). It seems worthwhile to note the suggestion of Yuan et al. (2012) in that *Megagraulos semicircularis* may be better accommodated with *Plesiagraulos* Chang, 1963, which has been documented in the *Sunaspis laevis-Sunaspidella rara* Zone (Taijiangian) of North China.

The *Tonkinella* Zone of the Machari Formation may be correlated with the *Tonkinella flabelliformis-Poriagraulos nanus* Zone of North China (Yuan et al., 2012), and comparable faunas have been also known from the *Ehmaniella* Zone of the Great Basin, North America (Sundberg, 1994). The succeeding *Ptychagnostus sinicus* Zone (Hong and Choi, 2015) can be equated with the

Geologic Age			Taebaek	Yeongwol	North China	South China	Australia
O	Early	Tremadocian	*Richardsonella*	*Yosimuraspis*	*Yosimuraspis*	*Hysterolenus-Onychopyge*	
			Pseudokoldinioidia		*Pseudokoldinioidia*	*Leiostegium-Shenjiawania*	
		Cambrian Stage 10	*Eosaukia*	*Fatocephalus*	*Mictosaukia*	*Mictosaukia-Fatocephalus*	*Mictosaukia perplexa*
					Wanwanaspis-Plethopeltella	*Archaeuloma-Leiagnostus*	*Neoagnostus Shergoldia*
						Lotagnostus-Hedinaspis	*Sinosaukia impages*
			Quadraticephalus		*Changia*		
		Jiangshanian	*Asioptychaspis*		*Ptychaspis-Tsinania*	*Probilacunaspis-Peichiashania*	*Rhaptagnostus*
	Furongian		*Kaolishania*		*Kaolishania*	*Eolotagnostus-Kaolishaniella*	*Peichiashania*
				Pseudoyuepingia		*Rhaptagnostus-Onchonotellus*	*Wentsuia-Rhaptagnostus*
				Agnostotes	*Maladioidella*	*Agnostotes*	*Irvingellatropica*
		Paibian		*Eochuangia*	*Changshania-Irvingella*	*Tomagnostus-Corynexochus*	
			Chuangia	*Eugonocare*	*Chuangia*		*Stigmatoadiloma*
				Hancrania		*Agnostus-Proceratopyge*	*Erixaniumsentum*
			Prochuangia Fenghuangella	*Proceratopyge*	*Prochuangia*		*Proceratopyge*
				Glypt reticulatus		*Glypt reticulatus*	*Glypt reticulatus*
CAMBRIAN	Cambrian Series 3	Guzhangian	*Liostracinasimesi*	*Glyptagnostus stolidotus*	*Neodrepanura*	*Glyptagnostus stolidotus*	*Glyptagnostus stolidotus*
			Neodrepanura			*Linguagnostus*	*Acmarachis*
			Jiulongshania		*Blackwelderia*	*Proagnostus*	*Erediaspis*
					Damesella	*Lejopyge laevigata*	*Damesella-Ferenepea*
							Lejopyge laevigata
		Drumian		*Lejopyge armata*	*Liopeishania*	*Lejopyge armata*	*Goniagnostus nathorsti*
					Taitzuia-Poshania	*Goniagnostus nathorsti*	
			Amphoton		*Amphoton*	*Ptychagnostus punctuosus*	*Doryagnostus Pt. punctuosus*
			Crepicephalina	*Ptychagnostus atavus*	*Crepicephalina Megagraulos Inouyella*	*Ptychagnostus atavus*	*Euragnostus Ptychagnostus atavus*
		Cambrian Stage 5	*Bailiella*	*Ptychagnostus sinicus*	*Bailiella*	*Ptychagnostus gibbus*	*Ptychagnostus gibbus*
			Mapania(?)	*Tonkinella*	*Tonkinella-Poriagraulos Inouyops*	*Peronopsis*	*Pentagnostus shergoldi*
				Megagraulos Metagraulos	*Metagraulos Sunaspis-Sunaspidella*		*Ptychagnostus praecurrens*
			Elrathia		*Sinopagetia Ruichengaspis Hsuchuangia-Ruichengella*		*Pentagnostus anabarensis*
					Shantungaspis	*Oryctocephalus*	
					Yaojiayuella		
	Cambrian Series 2	Cambrian Stage 4	*Redlichia*		*Qiaoatouaspis*	*Ovatoryctocara-Bathynotus*	*Xystriduranegrina-Redlichiaforresti*
					Redlichia Pteroredlichia	*Protoryctocephalus Arthricocephalites*	

Fig. 7. Correlation of the Cambrian trilobite biozones of Korea with those of North China, South China, and Australia.

Ptychagnostus gibbus Zone of South China (Peng and Robison, 2000) and Australia (Kruse et al., 2009), and also with the *Bailiella lantenoisi* Zone and presumably *Tonkinella flabelliformis-Poriagraulos nanus* Zone of North China (Yuan et al., 2012).

5.3 Drumian

The *Ptychagnostus atavus* Zone, that defines the base of the global Drumian Stage (Babcock et al., 2007), has recently been recognized in the Machari Formation of the Yeongwol Group (Hong and Choi, 2015) and is correlated with those of South China (Peng and Robison, 2000), Australia (Kruse et al., 2009), and Laurentia (Babcock et al., 2007). In China, the *Ptychagnostus atavus* Zone of South China has been collectively correlated with the *Inouyella*, *Crepicephalina*, and partly *Amphoton* zones of North China (Zhou and Zhen, 2008). The *Crepicephalina* and *Amphoton* zones of the Taebaek Group (Kang and Choi, 2007) can be equated with those of North China (Yuan et al., 2012).

The *Lejopyge armata* Zone represents the youngest biozone of the Drumian Stage in the Taebaeksan Basin (Fig.

Geologic Age			Taebaek	Yeongwol	North China	South China	Australia
ORDOVICIAN	Middle	Darriwilian	*Dolerobasilicus*				
		Daipingian					
	Early	Floian	*Kayseraspis*	*Kayseraspis*			
		Tremadocian		*Shumardia*		*Illaenus*–*Guizhouhystricus*	
			Protopliomerops		*Asaphopsoides*	*Conophrys*–*Asaphopsoides*	
			Asaphellus		*Asaphellus*		
				Kainella		*Apatokephalus*–*Taoyuania*	
					Wangliangtingia	*Dactylocephalus*–*Asaphellus*	
						Wangliangtingia	
			Richardsonella	*Yosimuraspis*	*Yosimuraspis*	*Hysteolenus*–*Onychopyge*	
CAMB.	Furongian	Cambrian Stage10	*Pseudokoldinioidia*		*Pseudokoldinioidia*	*Leiostegium*–*Shenjiawania*	

Fig. 8. Correlation of the Ordovician trilobite biozones of Korea with those of North China, South China, and Australia.

7). *Lejopyge armata* has been globally documented from Drumian strata including South China (Peng and Robison, 2000), Queensland (Öpik, 1967), Tasmania (Jago, 1976), Kazakhstan (Ergaliev, 1980), and the Himalaya (Jell and Hughes, 1997). In South China, *L. armata* first appears in the upper *Goniagnostus nathorsti* Zone and ranges up into the *Lejopyge laevigata* and *Proagnostus bulbus* zones (Peng and Robison, 2000), whereas in North America and Greenland *L. armata* is known from the upper part of the *L. laevigata* Zone (Robison, 1984). *Lejopyge armata* has been generally known to occur earlier than *L. laevigata* (Dalman, 1828), which defines the base of the global Guzhangian Stage (Peng et al., 2009).

5.4 Guzhangian

Kang and Choi (2007) correlated the *Jiulongshania* Zone of the Daegi Formation with the *Damesella* Zone of the Changhia Formation of North China, while Park et al. (2013) demonstrated that the *Jiulongshania* Zone of the Sesong Formation can be correlated with the *Blackwelderia* Zone of the Kushan Formation of North China, on the comparison of successive occurrences of *Jiulongshania* species. Therefore, the *Jiulongshania* Zone of the Taebaek Group can be collectively correlated with the *Damesella* and *Blackwelderia* zones of North China (cf. Yuan et al., 2012).

Neodrepanura, *Liostracina*, and *Teinistion* are important members of the *Neodrepanura* Zone of the Taebaek Group (Park and Choi, 2011). *Neodrepanura* occurs abundantly in the *Neodrepanura* Zone of North China (Zhang and Jell, 1987) and was also reported from the *Linguagnostus reconditus* Zone of South China with reservation (Peng et al., 2004a). *Liostracina* has been widely documented and often employed as a zonal taxon in China: namely, *Liostracina bella* Zone of South China (Peng et al., 2004a) and *Liostracina* Zone of Xinjiang (Lin et al., 1992). *Liostracina* was also known to occur in the *Glyptagnostus stolidotus* Zone of Australia (Öpik, 1967) and Antarctica (Jago and Cooper, 2005). *Teinistion* has a relatively long stratigraphic range from the upper part of the *Damesella* Zone to the lower part of the *Neodrepanura* Zone in North China (Zhang and Jell, 1987; Guo et al., 1996; Zhou and Zhen, 2008; Yuan et al., 2012), while it is more or less restricted within the *Liostracina* Zone of Xinjiang (Lin et al., 1992) and the *Wanshania wanshanensis* and *Liostracina bella* zones of South China (Peng et al., 2004a). In summary, the *Neodrepanura* Zone is confidently correlated with the *Neodrepanura* Zone of the Kushan Formation of North China (Zhang and Jell, 1987) and the upper biozones of the Guzhangian Stage elsewhere (Peng et al., 2009).

The *Liostracina simesi* and *Glyptagnostus stolidotus* zones of the Taebaeksan Basin represent the youngest biozones of the Cambrian Series 3 in Korea (Park and Choi, 2011; Hong and Choi, 2015). *Liostracina* has been largely known from the Guzhangian Stage of China (Zhang and Jell, 1987; Lin et al., 1992; Peng et al., 2004a). It is however noteworthy that *L. simesi* has been known to occur in association with *Glyptagnostus stolidotus* in Antarctica (Jago and Cooper, 2005), which provides a reference for correlation of the *Liostracina simesi* Zone with the *Glyptagnostus stolidotus* Zone and correlatives. The *Glyptagnostus stolidotus* Zone has been widely recognized in Australia (Öpik, 1961, 1963, 1967), South China (Jegorova et al., 1963; Lu and Lin, 1989; Peng and Robison, 2000), and Tarim (Wang et al., 1985). *Glyptagnostus stolidotus* has also been recovered from the *Crepicephalus* Zone of Laurentia (Palmer, 1962) and Antarctica (Cooper et al., 1996; Jago and Cooper, 2005).

5.5 Paibian

Trilobite biozones belonging to the Paibian Stage are

well documented in the Taebaeksan Basin: they are the *Fenhuangella laevis*, *Prochuangia mansuyi*, and *Chuangia* zones of the Taebaek Group and the *Glyptagnostus reticulatus*, *Proceratopyge tenuis*, *Hancrania brevilimbata*, *Eugonocare longifrons*, and *Eochuangia hana* zones of the Yeongwol Group (Choi et al., 2004b, 2008; Park and Choi, 2011; fig. 7).

The *Glyptagnostus reticulatus* Zone has been employed to define the base of the Furongian Series (Peng et al., 2004b) and the Paibian Stage and has been recognized around the world. The *Proceratopyge tenuis* Zone can be correlated with the *Agnostus inexpectans*-*Proceratopyge protracta* Zone of South China (Lu and Lin, 1989; Peng, 1992) and the *Proceratopyge cryptica* Zone of Australia (Öpik, 1967; Henderson, 1976; Shergold, 1982) in sharing species of *Proceratopyge*. The *Hancrania brevilimbata* Zone is rather difficult to correlate with other parts of the world, as most of the taxa are either long-ranging or endemic to Yeongwol. Nonetheless, it may be comparable with the upper part of the *Agnostus inexpectans*-*Proceratopyge protracta* Zone of South China (Lu and Lin, 1989; Peng, 1992) and the *Erixanium sentum* Zone of Australia (Öpik, 1967; Henderson, 1976; Shergold, 1982). The co-occurrence of *Eugonocare*, *Erixanium*, *Irvingella*, and *Proceratopyge* of the *Eugonocare longifrons* Zone provides its correlation with the Paibian biozones elsewhere: namely, the *Erixanium* Zone (Lu and Lin, 1989) and *Corynexochus plumula*-*Sinoproceratopyge* cf. *kiangshanensis* Zone of South China (Peng, 1992), and *Stigmatoa diloma* Zone of Australia (Öpik, 1967; Henderson, 1976; Shergold, 1982). *Eochuangia hana* occurs exclusively in the *Eochuangia hana* Zone. The co-occurrence of *Irvingella* and *Changshania* in Yeongwol (Choi and Kim, 2006) and North China (Lu and Qian, 1983; Qian, 1994; Zhang et al., 1995) provides a correlation of the *Eochuangia hana* Zone with the *Changshania conica*-*Irvingella taitzuhoensis* Zone (upper Paibian) of North China and part of the *Irvingella tropica* Zone of Australia (Shergold, 1982).

The *Fenghuangella laevis* Zone of the Taebaek Group is characterized by the association of *Fenghuangella*, *Placosema*, *Parachangshania*, and *Baikadamaspis*. *Fenghuangella* has been recovered from the *Wanshania wanshanensis* to *Chuangia subquadrangulata* zones of South China (Peng et al., 2004a) and from the *G. stolidotus* Zone in Kazakhstan (Ergaliev, 1980). *Placosema bigranulosum* was documented from the upper part of the *Liostracina bella* Zone to the lower part of the *Chuangia subquadrangulata* Zone of South China, equivalent to the *Glyptagnostus stolidotus* Zone to the lower part of the *G. reticulatus* Zone of South China (Peng et al., 2004a). *Parachangshania* has been known to occur exclusively in the *Chuangia* Zone of North China (Qian, 1994), which can be partly correlated with the *G. reticulatus* Zone (Zhou and Zhen, 2008). *Baikadamaspis* was originally reported from the *G. reticulatus* and *Homagnostus longiformis* zones of Kazakhstan (Ergaliev, 1980), and subsequently documented from the *Linguagnostus reconditus* to *Glyptagnostus reticulatus* zones of South China (Yuan and Yin, 1998; Peng et al., 2004a). In short, the *Fenghuangella laevis* Zone can be correlated with the *Prochuangia* Zone or lower part of the *Chuangia* Zone of North China and the *Glyptagnostus reticulatus* Zone of South China. The correlation of the *Fenghuangella laevis* Zone with the *G. reticulatus* Zone of South China warrants that the base of the Furongian Series in the Taebaek Group can be placed at the base of the *Fenghuangella laevis* Zone.

Prochuangia mansuyi has also been employed as a zonal taxon in North China (Qian, 1994), which can be correlated with the upper part of the *Glyptagnostus reticulatus* Zone and the lower part of the *Agnostus inexpectans*-*Proceratopyge protracta* Zone of South China (Peng, 1992). Specimens referable to *Maladioides coreanicus* were reported from the *Chuangia* Zone of North China (Zhu and Wittke, 1989; Qian, 1994). Hence, the *Prochuangia mansuyi* Zone of the Taebaek group can be equated with that of North China and less convincingly with the *Glyptagnostus reticulatus* and *Agnostus inexpectans*-*Proceratopyge protracta* zones of South China (Peng, 1992). The paucity of trilobite taxa in the *Chuangia* Zone does not allow a reliable correlation of the *Chuangia* Zone of the Taebaek Group with the biozones of other parts of the world, albeit it has been broadly correlated with the *Chuangia* Zone of North China (Sun, 1935; Qian, 1994).

5.6 Jiangshanian

Trilobite biozones assignable to the Jiangshanian Stage are rather poorly represented in the Taebaeksan Basin: they are the *Agnostotes orientalis* and *Pseudoyuepingia asaphoides* zones of the Yeongwol Group (Choi et al., 2004b, 2008) and the *Kaolishania* and *Asioptychaspis subglobosa* zones of the Taebaek Group (Sohn and Choi, 2007; Park et al., 2012; Park and Kihm, 2015).

The genus *Agnostotes*, one of the most widespread and short-ranging trilobites, is an index taxon for defining the base of the Jiangshanian Stage (Peng et al., 2012a). It has been reported to occur in the *Agnostotes clavatus*-*Irvingella angustilimbata* Zone of South China (Lu and Lin, 1989; Peng, 1992), *Agnostotes tianshanicus* Zone of Tarim (Wang et al., 1985), *Irvingella tropica* Zone of Australia (Öpik, 1963), *Pseudagnostus vastulus*-*Irvingella tropica* Zone of Kazakhstan (Ergaliev, 1980; Ergaliev et

al., 2014), *Irvingella-Cedarella felix* Zone of Siberia (Lazarenko, 1966), and *Proceratopyge rectispinata* fauna of northwestern Canada (Pratt, 1992). The association of *Irvingella* and *Agnostotes* is also known in South China (Peng, 1992), Australia (Öpik, 1963; Shergold, 1982), Siberia (Lazarenko, 1966) and Canada (Pratt, 1992), which provides a firm basis for intercontinental correlation of the *Agnostotes orientalis* Zone.

In general, members of the *Pseudoyuepingia asaphoides* Zone have a relatively long stratigraphic range from the middle Middle Cambrian to middle Late Cambrian (Peng and Robison, 2000) and thus are of limited biostratigraphic value. *Peratagnostus orientalis* is relatively widespread in distribution and provides a basis for correlation of the zone with other parts of the world: i.e., the *Proceratopyge fenghwangensis* to *Agnostotes orientalis-Sinoproceratopyge kiangshanensis* zones (Lu and Lin, 1989) and *Rhaptagnostus ciliensis-Onchonotellus* cf. *kuruktagensis* zones of South China (Peng, 1992), *Wentsuia iota-Rhaptagnostus apsis* Zone of Australia (Shergold, 1980), *Irvingella-Cedarella felix* Zone of the Siberian Platform (Lazarenko, 1966), and Upper Cambrian of Alaska (Palmer, 1968).

Kaolishania was originally erected from the Changshanian of Shandong Province, China (Sun, 1924) and has since been widely documented from the *Kaolishania* Zone of North China (Kobayashi, 1933; Sun, 1935; Zhang and Jell, 1987; Zhu and Wittke, 1989; Qian, 1994; Duan et al., 2005) and Korea (Kobayashi, 1935; Park et al., 2012). The upper part of the *Kaolishania* Zone of the Sagundari section (Park et al., 2012) lacks *Kaolishania* species, but yields *Acanthometopus* sp., which provides a correlation of the upper part of the *Kaolishania* Zone with the *Acanthometopus* Zone of northeast China (Qian, 1994). *Kaolishania* has been reported from the Furongian of Bhutan (Hughes et al., 2011). In summary, the *Kaolishania* Zone of the Sesong Formation can be correlated collectively with the *Kaolishania* and *Acanthometopus* zones of North China (Zhang and Jell, 1987, Zhu and Wittke, 1989; Qian, 1994; Duan et al., 2005).

Asioptychaspis subglobosa was previously known to occur in the Changshanian *Tsinania canens* Zone of Liaoning Province (Kobayashi, 1933) and the *Ptychaspis-Tsinania* Zone of Shandong Province (Zhang and Jell, 1987), North China. *Tsinania canens* was also reported from the *Ptychaspis-Tsinania* Zone of North China (Walcott, 1905; Sun, 1935; Resser and Endo, 1937; Zhang and Jell, 1987). Consequently, the *Asioptychaspis subglobosa* Zone of the Hwajeol Formation (Sohn and Choi, 2007) can be correlated with the *Ptychaspis-Tsinania* Zone of North China with confidence.

5.7 Cambrian Stage 10

Trilobite biozones referable to the Cambrian Stage 10 are at present imperfectly documented in the Taebaeksan Basin: they are the *Quadraticephalus, Eosaukia, Pseudokoldinioidia* and *Richardsonella* zones of the Taebaek Group (Sohn and Choi, 2007; Lee and Choi, 2007, 2011) and the *Fatocephalus hunjiangensis* Zone of the Yeongwol Group (Sohn and Choi, 2002).

The genus *Quadraticephalus* has been reported from the *Changia* (or *Quadraticephalus*) and *Mictosaukia* zones of North China (Kobayashi, 1933; Zhang and Jell, 1987; Duan et al., 2005; Zhou and Zhen, 2008) and the Assemblage 1 (Paytonian) of the Amadeus Basin, Australia (Shergold, 1991). *Hamashania* was known to be endemic to North China and Korea (Sohn and Choi, 2005a), but has recently been documented in the faunal unit X of the Bonaparte Basin, Australia (Shergold et al., 2007). Specimens assignable to *Lophosaukia* have been reported from Australia, China, Vietnam, and Thailand: *Lophosaukia* from Australia is the oldest in occurrence from the *Rhaptagnostus bifax–Neoagnostus denticulatus* Zone; in North China it has been documented from the *Tsinania* Zone or simply Fengshanian strata (Sun, 1924; Kobayashi, 1933; Qiu et al., 1983; Zhang and Jell, 1987; Duan et al., 2005); and *Lophosaukia jiangnanensis* from South China is known from the *Lotagnostus americanus* Zone (Lu and Lin, 1984) and the slightly older *Probilacunaspis nasalis-Peichiashania hunanensis* Zone (Peng, 1992). In summary, the *Quadraticephalus* Zone can be equated with the *Changia* (or *Quadraticephalus*) Zone of North China.

The *Eosaukia* Zone has been correlated with the *Mictosaukia* Zone of North China, based on the co-occurrence of *Mictosaukia* and *Eosaukia* (Lee and Choi, 2011). Although correlation of the *Eosaukia* fauna with those outside of the Sino-Korean Craton is rather difficult; some species referable to *Eosaukia* have been known to occur in the upper Furongian of South China. Accordingly, the *Eosaukia* Zone can be correlated with an interval including the *Mictosaukia striata-Fatocephalus* Zone and possibly slightly older horizons of South China. The *Eosaukia* Zone is also comparable, but less convincingly, with the upper Paytonian '*Mictosaukia*' *perplexa* Zone of Queensland based on the occurrences of *E. perplexa* and *E. solitaria* and with the Assemblage 1 of Northern Territory on *E.* sp. cf. *E. walcotti* in Australia (Shergold, 1991).

Pseudokoldinioidia Endo, 1944 is a missisquoiid trilobite genus endemic to Korea and China, ranging in age from late Jiangshanian to early Tremadocian (Lee and Choi, 2007). On the other hand, *Onychopyge* displays a more widespread distribution along the early Paleozoic

peri-Gondwanan regions including North China, South China, Australia, Mexico, Bolivia, and Argentina. The association of *Pseudokoldinioidia* and *Onychopyge* suggests a reliable correlation of the *Pseudokoldinioidia* Zone with the latest Cambrian trilobite assemblages of North China, South China, Australia, South America, and Mexico (Lee and Choi, 2007).

The *Richardsonella* Zone has not yet been studied in detail, but was considered to be contemporaneous to the *Richardsonella-Platypeltoides* Zone of North China (Lee and Choi, 2007). Choi et al. (2003) suggested that the Cambrian–Ordovician boundary in the Taebaek Group may possibly be placed within the *Richardsonella* Zone of the Dongjeom Formation, based on the observation of *Yosimuraspis* in the zone.

The *Fatocephalus* fauna has been correlated with the upper Furongian trilobite faunas of China (Sohn and Choi, 2002): i.e., the *Mictosaukia-Fatocephalus* and *Pseudokoldinioidia perpetis* zones of North China (Chen et al., 1988; Zhou and Zhen, 2008) and the *Mictosaukia striata-Fatocephalus*, *Leiostegium constrictum-Shenjiawania brevica* and lower *Hysterolenus-Onychopyge* zones of South China (Peng, 1990, 1992).

5.8 Tremadocian

The Tremadocian trilobite biozones include the *Yosimuraspis vulgaris*, *Kainella euryrachis* and *Shumardia pellizzarii* zones of the Yeongwol Group and the *Asaphellus* and *Protopliomerops* zones of the Taebaek Group (Fig. 8).

The genus *Yosimuraspis* has been known to occur in the *Richardsonella* Zone of the Taebaek Group (Lee and Choi, 2007) and hence the *Yosimuraspis vulgaris* Zone of Yeongwol can be correlated with part of the *Richardsonella* Zone of Taebaek. The faunal assemblages closely comparable to the *Yosimuraspis vulgaris* Zone are well represented in North China (Chen et al., 1983, 1985, 1988; Zhou and Zhang, 1985; Duan et al., 1986). The association of *Jujuyaspis* and *Yosimuraspis* in the zone provides a basis for intercontinental correlation of the *Yosimuraspis vulgaris* Zone with the lower Tremadocian of the Bonaparte Basin, Australia (Shergold et al., 2007) and other parts of the world (Kim and Choi, 2000a).

Kainella was previously recorded from the *Wangliangtingia* Zone of North China (Duan et al., 1986) to which the *Kainella euryrachis* Zone can be correlated. *Leiostegium* has been frequently documented from uppermost Cambrian to Lower Ordovician strata of China (Zhou and Zhang, 1978, 1985; Chen et al., 1980, 1985, 1988; Peng, 1984; Duan et al., 1986; Lu and Zhou, 1990) and Australia (Shergold, 1975; Jell, 1985).

Trilobite faunas comparable to the *Shumardia pellizzarii* Zone have been well documented from the upper Tremadocian strata of North China and Australia. The *Asaphellus* Zone (Chen et al., 1983; Zhou and Fortey, 1986) and *Koraipsis* Zone (Duan et al., 1986) of North China comprise some trilobite genera in common with the *Shumardia pellizzarii* Zone including *Asaphellus, Hystricurus, Koraipsis*, and *Dikelokephalina*. Fairly abundant and diverse upper Tremadocian trilobite faunas were reported from South China (Peng, 1990). Although their faunal content is quite different from that of the *Shumardia pellizzarii* Zone, the occurrence of some widespread genera such as *Asaphellus, Shumardia,* and *Apatokephalus* allows the correlation of the *Shumardia pellizzarii* Zone with part of the *Acanthograptus sinensis-Tungtzuella* Zone of Yangtze Platform and the *Apatokephalus latilimbatus-Taoyuania affinis* or the *Shumardia acutifrons-Asaphopsoides* assemblage zones of the Jiangnan Slope Belt (Peng, 1990). An upper Tremadocian trilobite assemblage from the Pacoota Sandstone of Australia (Shergold, 1991), designated as Assemblage 2, shows a close similarity with the *Shumardia pellizzarii* Zone in yielding *Shumardia, Apatokephalus, Hystricurus, Koraipsis,* and *Asaphellus*.

Asaphellus is a cosmopolitan trilobite genus in the Tremadocian, which provides a basis for correlation of the *Asaphellus* Zone of the Taebaek Group (Kim et al., 1991) with the upper Tremadocian biozones of North China (Zhou and Fortey, 1986), South China (Peng, 1990), and Australia (Shergold, 1975). Kim et al (1991) stated that the *Protopliomerops* Zone may possibly be bracketed within the upper Tremadocian.

5.9 Floian

The *Kayseraspis* Zone of the Taebaeksan Basin has been known to occur in the Taebaek and Yeongwol groups (Kim et al., 1991; Choi, 1998b). Comparable trilobite faunas to the *Kayseraspis* Zone have been documented in the Yeli Formation of North China (Zhou and Fortey, 1986) and the *Conophyrys-Asaphopsoides* Zone of South China (Peng, 1990) which were however been dated as late Tremadocian. In this paper, the *Kayseraspis* Zone is assigned to the Floian, based on information of associated conodont faunal assemblages (Seo et al., 1994). The *Kayseraspis* Zone can also be compared with the *Kayserapsis* cf. *brackebuschi* Assemblage-Zone of Canning Basin, Australia (Laurie and Shergold, 1996) and a trilobite faunule of Tasmania (Jell and Stait, 1985) in association of *Kayseraspis* and *Asaphopsoides*.

5.10 Daipingian/Darriwilian

Choi et al. (2001) proposed the *Dolerobasilicus* Zone for the fossiliferous interval of the Jigunsan Formation in

Taebaek. The conodont faunal assemblage of the Jigunsan Formation (Lee and Lee, 1986) indicates a Darriwilian age.

6 Conclusion

Trilobites are among the most diverse and abundant fossil groups in Korea and occur in the Cambrian-Ordovician Joseon Supergroup of the Taebaeksan Basin. The Cambrian-Ordovician trilobites of the Joseon Supergroup have been intensively studied during the last quarter century, focusing on taxonomic revision, refined biostratigraphic zonation, and paleogeographic implications. A total of 224 species have hitherto been known to occur in the Joseon Supergroup of the Taebaeksan Basin: 99 and 111 species were reported in the Taebaek and Yeongwol groups, respectively, whilst 14 species were described from the Mungyeong Group.

Contrasting trilobite faunal contents of the Taebaek and Yeongwol/Mungyeong groups resulted in two separate biostratigraphic schemes for the Cambrian–Ordovician of the Taebaeksan Basin: 22 biozones or fossiliferous horizons were recognized in the Taebaek Group; 19 zones were established in the Yeongwol Group; and four biozones were known from the Mungyeong Group.

In the Taebaek Group, trilobites have been reported from all but the lowermost Jangsan and Myeonsan formations. The trilobite biozones of the Taebaek Group have been intensively re-investigated during the last decade, except for the Myobong Formation. The trilobite faunal assemblages of the Taebaek Group form a basis for establishing 22 biozones: in ascending order, *Redlichia*, *Elrathia*, *Mapania* (?), *Bailiella*, *Crepicephalina*, *Amphoton*, *Jiulongshania*, *Neodrepanura*,, *Liostracina simesi*, *Fenghuangella laevis*, *Prochuangia mansuyi*, *Chuangia*, *Kaolishania*, *Asioptychaspis subglobosa*, *Quadraticephalus*, *Eosaukia*, *Pseudokoldinioidia*, *Richardsonella*, *Asaphellus*, *Protopliomerops*, *Kayseraspis*, and *Dolerobasilicus* zones.

Trilobites of the Yeongwol Group have been thoroughly studied during the last two decades, which resulted in the recognition of 19 trilobite biozones within the group: in ascending order, *Metagraulos sampoensis*, *Megagraulos semicircularis*, *Tonkinella*, *Ptychagnostus sinicus*, *Ptychagnostus atavus*, *Lejopyge armata*, *Glyptagnostus stolidotus*, *Glyptagnostus reticulatus*, *Proceratopyge tenuis*, *Hancrania brevilimbata*, *Eugonocare longifrons*, *Eochuangia hana*, *Agnostotes orientalis*, *Pseudoyuepingia asaphoides*, *Fatocephalus hunjiangensis*, *Yosimuraspis vulgaris*, *Kainella euryrachis*, *Shumardia pellizzarii*, and *Kayseraspis* zones.

The lower Paleozoic trilobites of the Mungyeong Group has not yet been re-evaluated, but the biozones of the Mungyeong Group established by Kobayashi (1961) are in ascending order the *Redlichia*, *Palaeolenus*, *Ptychoparia-Dawsonia*, and *Kootenia* zones.

All of these trilobite biozones of the Taebaeksan Basin can be correlated well with those of North China, South China, and Australia.

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