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Middle Cambrian trilobites and biostratigraphy of the Daegi Formation (Taebaek Group) in the Seokgaejae section, Taebaeksan Basin, Korea

Imseong Kang
Duck K. Choi*
School of Earth and Environmental Sciences, Seoul National University, Seoul 151-742, Korea

ABSTRACT: The Daegi Formation in the Taebaeksan Basin of Korea is composed of shallow marine carbonate facies and has been known to yield relatively diverse invertebrate fossils of middle Cambrian age. This paper describes seventeen trilobite species belonging to fifteen genera from the Daegi Formation exposed in the Seokgaejae section, located at southeastern corner of the Taebaeksan Basin. They comprise two agnostoid species (*Ammagnostus laiwuensis* and *Ammagnostus* sp.) and fifteen polymerid taxa (*Dorypyge richthofeni*, *Amphoton deois*, *Blackwelderia* sp., *Teinistion*? sp., *Palaeadotes*? sp., *Anomocarella temenus*, ptychopariid gen. and sp. indeterminate., *Changqingia deprati*, *Crepicephalina damia*, *Cyclolorenzella rotundata*, *Cyclolorenzella* sp., *Proasaphiscus* sp., *Manchuriella macar*, *Ignotogregatus manholi*, and *Metanomocarella tumida*). The stratigraphic distribution of these trilobites provides a basis for establishment of new trilobite zones within the formation: i.e., the *Crepicephalina*, *Amphoton*, and *Cyclolorenzella* zones in ascending order. The *Crepicephalina* Zone is dominated by *Crepicephalina damia*, *Manchuriella macar*, *Ignotogregatus* sp. cf. *I. manholi*, and *Ammagnostus laiwuensis*. The *Amphoton* Zone is recognized by the restricted occurrence of *Amphoton deois* and dominance of *Dorypyge richthofeni*. The *Cyclolorenzella* Zone is characterized by the occurrence of *Cyclolorenzella rotundata* and some damesellid trilobites. These three biozones belong to middle to upper middle Cambrian in age and are closely correlated with the *Crepicephalina*, *Amphoton*, and *Damesella–Yabeia* zones of North China, respectively.

Key words: middle Cambrian, trilobites, Korea, biostratigraphy, correlation

1. INTRODUCTION

The Daegi Formation of the Taebaek Group in the Taebaeksan Basin is characterized by predominance of carbonate rocks and has been known to yield relatively diverse invertebrate fossils of middle Cambrian age (Kobayashi, 1935, 1960). Kobayashi (1935, 1960) reported eleven genera and nineteen species of trilobites, two genera and two species of brachiopods, and one genus and two species of hyolithes from the formation, and proposed in ascending order the *Megagraulos*, *Solenoparia*, and *Olenoides* zones within the formation (Kobayashi, 1966). The biozones of the Daegi Formation were correlated with those of the Changhian Stage (middle Cambrian) in North China (Kobayashi, 1966). However, most of the species erected by Kobayashi (1935, 1960) were based on a small number of specimens and often inadequately described. These biozones have not been subsequently recognized in the Taebaeksan Basin and their stratigraphic positions within the Daegi Formation were poorly documented.

Previous geological studies on the Daegi Formation in Korea have mainly focused on lithostratigraphy, sedimentology, diagenesis, and geochemistry (Cheong, 1969; Yun, 1978; Kim and Park, 1981; Park and Han, 1986; Park et al., 1987; Park and Han, 1987; Kwon et al., 2006), whereas the paleontological approaches have seldom been made during the last forty years. This study primarily aims to describe the middle Cambrian trilobites from the Daegi Formation based on a number of new collections, to provide a refined biostratigraphic zonation of the formation, and to correlate it with coeval zones of North China.

2. GEOLOGIC SETTING

The Taebaeksan Basin is located at the central-eastern part of the Korean peninsula (Fig. 1) and comprises mixed carbonate–siliciclastic sedimentary rocks of Joseon Supergroup (Cambrian–Ordovician) and dominantly siliciclastic Pyeongan Supergroup (Carboniferous–Permian). The Joseon Supergroup has been differentiated into five groups based on distinct lithologic successions and geographic distribution (Fig. 1): the Taebaek, Yeongwol, Yongtan, Pyeongchang, and Mungyeong groups (Choi, 1998). The Taebaek Group occupies the eastern half of the Taebaeksan Basin (Fig. 1) and is composed of in ascending order the Jangsan/Myeonsan, Myobong, Daegi, Sesong, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan, and Duwibong formations (Kobayashi, 1966; Choi, 1998; Choi and Chough, 2005). The Cambrian–Ordovician boundary had been conventionally placed at the boundary between the Hwajeol and Dongjeom formations (Kobayashi, 1966), but recently it was suggested that the Cambrian–Ordovician boundary should be placed at the interval of the kainellid-dominated fauna within the lower part of the Dongjeom Formation (Choi et al., 2003).

The Daegi Formation, 200–300 m thick, is predominantly composed of milky white to light gray, massive to thin-bed-

*Corresponding author: dkchoi@snu.ac.kr

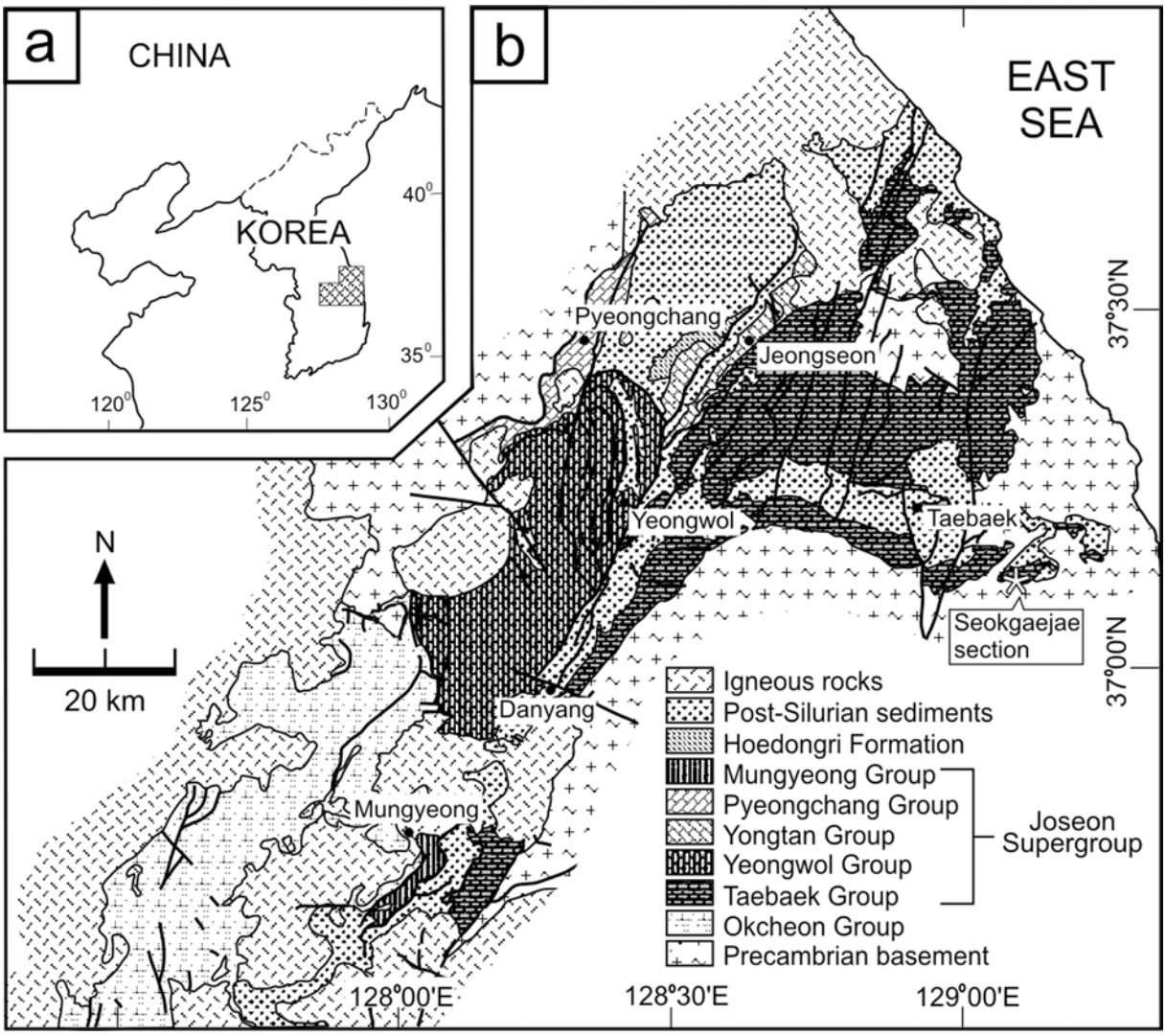

Fig. 1. Locality maps. (a) Map of the Korean peninsula showing the position of (b); (b) simplified geologic map showing the distribution of the Joseon Supergroup in the Taebaeksan Basin, Korea. The white asterisk in the lower right of the Taebaeksan Bain represents the fossil locality, the Seokgaejae section (modified from Choi, 1998).

ded limestone, and oolitic and dolomitic limestone and yields middle middle Cambrian trilobites (Kobayashi, 1935, 1966). It rests conformably on the mudstone-dominated Myobong Formation, which contains late early Cambrian to early middle Cambrian trilobite biozones; i.e., *Redlichia*, *Elrathia*, *Mapania*, and *Bailiella* zones in ascending order (Kobayashi, 1935, 1966). The Daegi Formation is conformably overlain by mudstone- and sandstone-dominated Sesong Formation of late middle Cambrian to early Furongian (or upper Cambrian) age (Kobayashi, 1935, 1966; Choi et al., 2004a; Kwon et al., 2006).

The Daegi Formation was interpreted to form in a shallow-marine setting, such as shallow shelf, lagoons, ooid shoals, or back-reef of reef mounds (Cheong, 1969; Yun, 1978; Kim and Park, 1981; Park and Han 1986; Park et al., 1987; Park and Han 1987). Recently Kwon et al. (2006) differentiated 14 facies associations from the Taebaek Group, including two facies associations within the Daegi Formation. The subtidal shoal and back shoal association in the lower part of the Daegi Formation includes oncoid and ooid grainstone and shale facies, while the overlying shallow subtidal and intertidal association is characterized by an alternation of relatively thick (more than a few meters) anastomosing and bioturbated limestone beds. The thick carbonate succession of the Daegi Formation is thought to have been deposited by rapid progradation of early and late highstand subtidal carbonates, which caused a drastic decrease in shallow subtidal zone and eventually resulted in reduction of carbonate productivity in the uppermost Daegi Formation (Kwon et al., 2006).

3. FOSSIL LOCALITY

All of trilobite specimens described in this study were

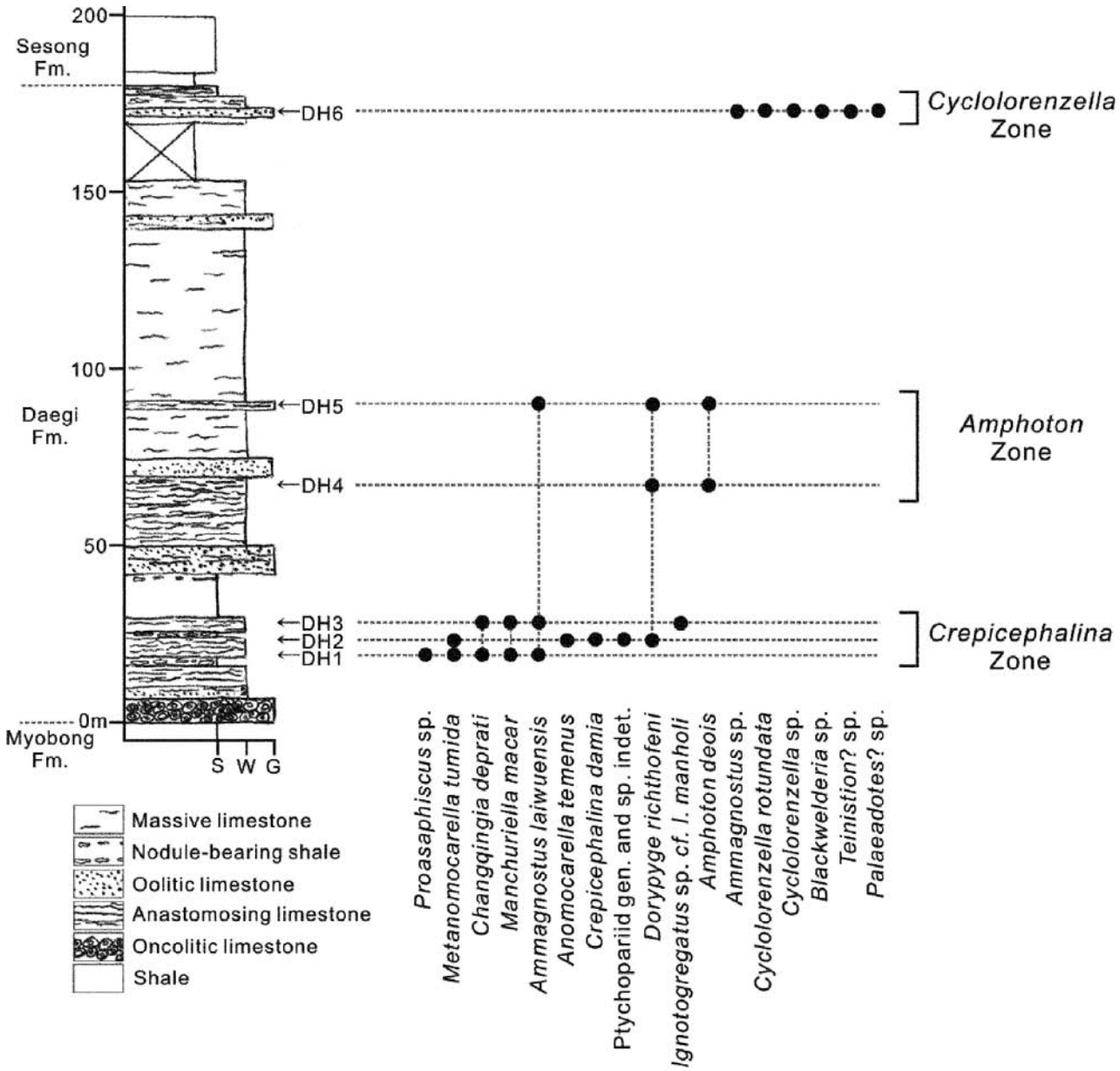

Fig. 2. Lithologic column of the Daegi Formation at the Seokgaejae section with occurrence of trilobites and stratigraphic distribution of the biozones. Numbers with prefix DH represent the sampling horizons from which trilobites were collected.

collected from a measured section, the Seokgaejae section (129°08′39″E and 37°04′19″N), exposed along a mountain trail near Mt. Myeonsan, Taebaek (Fig. 1). The Seokgaejae section is about 1,100 m in thickness, representing a nearly complete succession of the Taebaek Group (Choi et al., 2004a).

The Daegi Formation in the Seokgaejae section measures about 180 m thick (Fig. 2). The lower boundary of the formation is recognized by the lowest occurrence of oncolitic/oolitic grainstone bed. The lower part of the formation is characterized by oncolitic/oolitic grainstone, nodule-bearing shale, limestone-shale couplet, homogeneous mudstone, laminated mudstone, and cross-laminated mudstone. The middle to upper part consists predominantly of shallow-water carbonate facies, such as massive limestone, anastomosing limestone, oncolitic/oolitic grainstone, and bioclastic grainstone. The top of the formation is drawn at the base of the lowermost shale bed of the Sesong Formation, which rests on the massive oolitic grainstone or anastomosing wackestone/grainstone of the Daegi Formation (Choi et al., 2004a). Fossils were collected from six stratigraphic intervals (DH1 to DH6) in the Daegi Formation (Fig. 2). More than 350 trilobite specimens were recovered from limestone blocks or severely weathered nodule bearing shale. The collection

comprises cranidia, pygidia, librigenae, and hypostomes. These trilobites are often associated with inarticulate and articulate brachiopods and small shelly fossils.

4. BIOSTRATIGRAPHY AND CORRELATION

Kobayashi (1966) proposed three middle Cambrian trilobite zones in the Daegi Formation, namely the *Megagraulos*, *Solenoparia*, and *Olenoides* zones in ascending order. The *Megagraulos* zone was established from the lower part of the formation in the Dongjeom section and was known to comprise *Megagraulos coreanicus* Kobayashi, 1935 and *Kootenia damesi* Kobayashi, 1935. The *Solenoparia* zone occupies the lower to middle part of the formation in the Dongjeom section and yields a number of trilobites (Kobayashi, 1935, 1966): i.e., *Kootenia* sp., *Dorypyge richthofeni* Dames var. *laevis* Walcott, 1913, *Coosia coreanica* Kobayashi, 1935, *Eymekops expansus* (Kobayashi, 1935), *Eymekops hermias* (Walcott, 1911), *Eymekops carinatus* Kobayashi, 1960, *Solenoparia agno* (Walcott, 1905), *Solenoparia beroe* (Walcott, 1905), *Solenoparia laevis* Kobayashi, 1935, *Solenoparia* (?) *deprati* Kobayashi, 1935, *Solenoparia* sp. indet., *Koptura biloba* Kobayashi, 1935, *Asaphiscus* (?) sp., *Grandioculus* sp., *Anomocarella resseri* Kobayashi, 1935, *Anomocarella* cf. *tatian* (Walcott, 1905), and *Manchuriella minaformis* Kobayashi, 1935. It was suggested that the *Solenoparia* Zone might correlate with the Changhian Stage of North China (Kobayashi, 1966). The *Olenoides* Zone was supposedly established on an indeterminate form of *Olenoides* from the upper part of the formation in the Dongjeom section.

In this study, seventeen trilobite species belonging to fifteen genera were identified: i.e., *Ammagnostus laiwuensis* (Lorenz, 1906), *Ammagnostus* sp., *Dorypyge richthofeni* Dames, 1883, *Amphoton deois* (Walcott, 1905), *Blackwelderia* sp., *Teinistion*? sp., *Palaeadotes*? sp., *Anomocarella temenus* (Walcott, 1905), ptychopariid gen. and sp. indeterminate., *Changqingia deprati* (Kobayashi, 1935), *Crepicephalina damia* (Walcott, 1905), *Cyclolorenzella rotundata* (Resser and Endo, 1937), *Cyclolorenzella* sp., *Proasaphiscus* sp., *Manchuriella macar* (Walcott, 1911), *Ignotogregatus* sp. cf. *I. manholi* Zhang and Jell, 1987, and *Metanomocarella tumida* (Resser and Endo, 1937). This faunal composition is profoundly different from that listed by Kobayashi (1935, 1966). Accordingly, three biostratigraphic zones are proposed based on the stratigraphic distribution of trilobites in the Seokgaejae section: they are *Crepicephalina*, *Amphoton*, and *Cyclolorenzella* zones in ascending order (Fig. 2). The *Solenoparia* Zone of Kobayashi (1966) is renamed as the *Crepicephalina* Zone, because the taxonomic status of *Solenoparia* (see the remarks of *Changqingia deprati*) is unstable. On the other hand, the *Megagraulo*s and *Olenoides* zones are not recognized in this study. The *Megagraulos* Zone may be older than the *Crepicephalina* Zone, while the *Olenoides* Zone cannot be evaluated because *Olenoides*, the only component of the zone, was neither illustrated nor described.

The *Crepicephalina* Zone occupies about lower 30 m interval of the Daegi Formation in the Seokgaejae section (Fig. 2). It comprises ten trilobite species: *Ammagnostus laiwuensis*, *Dorypyge richthofeni*, *Anomocarella temenus*, ptychopariid gen. and sp. indeterminate, *Changqingia deprati*, *Crepicephalina damia*, *Proasaphiscus* sp., *Manchuriella*

<table>
<tr><td></td><td colspan="3">TAEBAEK, KOREA</td><td colspan="2">NORTH CHINA</td><td>SOUTH CHINA</td></tr>
<tr><td rowspan="11">Middle Cambrian</td><td colspan="2">Kobayashi, 1966</td><td>This study</td><td colspan="2">Zhang, 2003</td><td>Peng et al., 2004a</td></tr>
<tr><td rowspan="2">Sesong Fm.</td><td>Drepanura</td><td>Drepanura</td><td rowspan="2">Gushan Fm.</td><td>Drepanura</td><td>Liostracina bella</td></tr>
<tr><td>Stephanocare</td><td>Stephanocare</td><td>Blackwelderia</td><td>Wanshania wanshanensis</td></tr>
<tr><td rowspan="5">Daegi Fm.</td><td>Olenoides</td><td>Cyclolorenzella</td><td rowspan="5">Zhangxia Fm.</td><td>Damesella–Yabeia</td><td rowspan="3">Pianaspis sinensis</td></tr>
<tr><td></td><td></td><td>Leiopaishania</td></tr>
<tr><td>Solenoparia</td><td></td><td>Taitzuia–Poshania</td></tr>
<tr><td></td><td>Amphoton</td><td>Amphoton</td><td rowspan="2">Dorypyge richthofeni</td></tr>
<tr><td>Megagraulos</td><td>Crepicephalina</td><td>Crepicephalina</td></tr>
<tr><td rowspan="2">Myobong Fm.</td><td>Bailiella</td><td>Bailiella</td><td rowspan="2">Mantou Fm.</td><td>Bailiella–Lioparia</td><td rowspan="2">(Unnamed)</td></tr>
<tr><td>Mapania</td><td>Mapania</td><td>Poriagraulos</td></tr>
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Fig. 3. Correlation of the newly established middle Cambrian biozones of the Daegi Formation with coeval ones of North China and South China.

macar, *Ignotogregatus* sp. cf. *I. manholi*, and *Metanomocarella tumida*. The former two species range upwards into the *Amphoton* zone, while the latter eight species are confined to this zone. The *Crepicephalina* Zone of the Daegi Formation in Korea and of the Changhia Formation in North China shares a number of genera, including *Dorypyge*, *Anomocarella, Changqingia*, *Crepicephalina*, *Proasaphiscus*, *Manchuriella*, *Ignotogregatus*, and *Metanomocarella*.

The *Amphoton* Zone covers the intervals between 70 and 90 m above the base of the Daegi Formation in the Seokgaejae section, and is defined by the occurrence of *Amphoton deois*. 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 relative abundance. The co-occurrence of *Amphoton* and *Dorypyge* provides a correlation of the *Amphoton* Zone of the Daegi Formation with the *Amphoton* Zone of North China (Zhang and Jell, 1987) and with the *Dorypyge richthofeni* Zone of South China (Peng et al., 2004a).

The *Cyclolorenzella* Zone is recognized by the appearance of *Cyclolorenzella* and damesellids in the Seokgaejae section. This zone occupies a relatively short uppermost 5-m-thick interval of the Daegi formation and contains six species: *Ammagnostus* sp., *Blackwelderia* sp., *Teinistion*? sp., *Palaeadotes*? sp., *Cyclolorenzella rotundata* (Resser and Endo, 1937), and *Cyclolorenzella* sp. All of these taxa are documented for the first time in the formation. *Cyclolorenzella* has been widely reported in the upper middle Cambrian of North China (Zhang and Jell, 1987). Aside from *Cyclolorenzella*, the occurrence of some damesellids indicates that the *Cyclolorenzella* Zone of the Daegi Formation is comparable to the *Damesella–Yabeia* Zone of North China.

In summary, the *Crepicephalina*, *Amphoton* and *Cyclolorenzella* zones of the Daegi Formation are well correlated with the *Crepicephalina*, *Amphoton* and *Damesella–Yabeia* zones of North China, respectively (Fig. 3).

5. SYSTEMATIC PALEONTOLOGY

Morphological terms used herein are taken largely from Whittington and Kelly (1997) and descriptive terms for glabellar furrows and facial sutures follow those of Henningsmoen (1957). All of the specimens are deposited in the paleontological collections of Seoul National University (SNUP), Korea.

Order Agnostida Salter, 1864
Superfamily Agnostoidea McCoy, 1849
Family Agnostidae McCoy, 1849
Subfamily Ammagnostinae Öpik 1967

Genus *Ammagnostus* Öpik 1967

Type species: *Ammagnostus psammius* Öpik, 1967 from the *Glyptagnostus stolidotus* Zone, Queensland, Australia.

Remarks: A comprehensive account on the genus *Ammagnostus* has been recently made by Peng and Robison (2000), which is followed in this study. *Ammagnostus* has been known to occur in a relatively long stratigraphic interval ranging from the middle middle Cambrian (*Ptychagnostus atavus* Zone of South China) to middle Furongian (*Agnostotes orientalis* Zone of Korea) (Peng and Robison, 2000; Shergold et al., 2000; Choi et al., 2004b).

Ammagnostus laiwuensis (Lorenz, 1906)
Figure 4(a)–(f)

Agnostus fallax var. *laiwuensis* Lorenz, 1906, p. 82, pl. 4, figs. 7–8.
Agnostus chinensis Walcott, 1913, (in part) p. 99, pl. 7, figs. 4, 4a, 4b (not figs. 5–6).
Agnostus ozakii Resser and Endo, 1937, p. 159, pl. 30, fig. 7.
Agnostus comes Resser and Endo, 1937, (in part) p. 160, pl. 30, figs. 15, 17 (not fig. 16).
Hypagnostus latilimbatus (Lorenz): Kobayashi, 1938, (in part) p. 884, fig. 12 (not fig. 11).
Agnostus nodai Endo, 1944, (in part) p. 59, pl. 1, fig. 14 (not fig. 13).
Homagnostus incertus Robison, 1964, p. 531, pl. 82, figs. 16, 17, 19, 20.
Peronopsis comes (Resser and Endo): Lu et al., 1965, (in part) p. 47, pl. 5, fig. 11 (not fig. 10).
Peronopsis laiwuensis (Lorenz): Lu et al., 1965, p. 47, pl. 5, fig. 14.
Peronopsis ozakii (Resser and Endo): Lu et al., 1965, p. 48, pl. 5, fig. 18.
Peronopsis? *nodai* (Endo): Lu et al., 1965, (in part) p. 51, pl. 6, fig. 7 (not fig. 6).
Peronopsis incertus (Robison): Öpik, 1967, p. 139.
Peronopsis gullini Jago, 1976, p. 136, pl. 21, figs. 1–9.
Peronopsis ekip Jago, 1976, p. 139, pl. 21, figs. 10–16.
?*Oedorhachis crenias* Öpik, 1979, (in part) p. 42, pl. 8, fig. 5 (not figs. 1–4).
Iniospheniscus nodai (Endo): Sun, 1989, (in part) p. 86, pl. 6, figs. 11–13 (not fig. 14).
Peronopsis shandongensis Sun, 1989, p. 93, pl. 11, figs. 11–15, 19, 21–23, 25–28.
Peronopsis cylindrata Guo et al., 1996, p. 43, pl. 4, figs. 4–9, 11, 13, 18, 19, 21–23.
Peronopsis quadratiformis Guo et al., 1996, p. 44, pl. 5, figs. 5–10, 14.
Kormagnostus? *copelandi* Westrop et al., 1996, p. 815, figs. 14.1–14.11.
Ammagnostus laiwuensis (Lorenz): Peng and Robison,

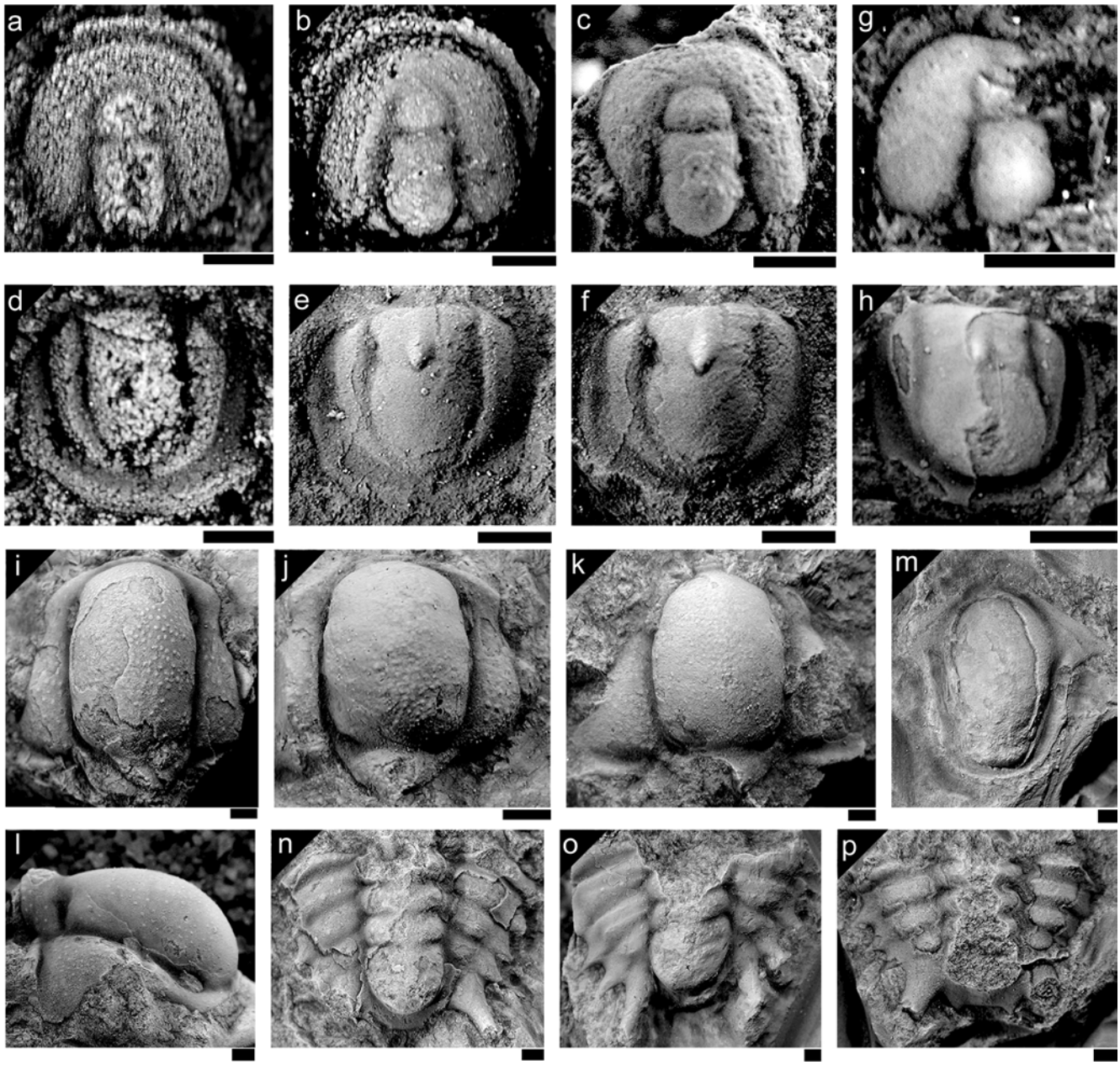

Fig. 4. Middle Cambrian trilobites from the Daegi Formation, the Seokgaejae section. Scale bars are 1mm long. (a)–(f) *Ammagnostus laiwuensis* (Lorenz, 1906). (a) SNUP3501, testaceous cephalon, DH3. (b) SNUP3502, testaceous cephalon, DH3. (c) SNUP3503, exfoliated cephalon, DH5. (d) SNUP3504, testaceous pygidium, DH3. (e) SNUP3505, mostly exfoliated pygidium, DH5. (f) SNUP3506, mostly exfoliated pygidium, DH5. (g)–(h) *Ammagnostus* sp. (g) SNUP3507, exfoliated cephalon, DH6. (h) SNUP3508, partly exfoliated pygidium, DH6. (i)–(p) *Dorypyge richthofeni* Dames, 1883. (i) SNUP3509, partly exfoliated cranidium, DH5. (j) SNUP3510, testaceous cranidium, DH5. (k) SNUP3511, exfoliated cranidium, DH5. (l) SNUP3512, lateral view of partly exfoliated cranidium, DH5. (m) SNUP3513, mostly exfoliated hypostome, DH5. (n) SNUP3514, partly exfoliated pygidium, DH5. (o) SNUP 3515, exfoliated pygidium, DH5. (p) SNUP3516, partly exfoliated pygidium, DH5.

2000, p. 27, fig. 20 (for additional synonymy).

Material examined: Two cephala from DH1, 30 cephala and 12 pygidia from DH3, and one cephalon and five pygidia from DH5.

Occurrence: *Crepicephalina* and *Amphoton* zones of the Daegi Formation; middle Cambrian of China, Australia, and Laurentia (cf. Peng and Robison, 2000).

Remarks: Specimens of *A. laiwuensis* from the Daegi Formation are generally poorly preserved and display a range of morphological variation. The morphological variation is particularly evident in pygidia: some have a conical pygidial axis with acuminate rear, whereas others are characterized by a more or less parallel-sided axis with broadly

rounded rear. A broad spectrum of morphological variability has been well demonstrated in a collection from Hunan of South China (Peng and Robison, 2000).

Ammagnostus sp.
Figure 4(g)–(h)

Material examined: Two cephala and one pygidium from DH6.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation.

Remarks: This species is distinguished from *Ammagnostus laiwuensis* from the lower part of the Daegi Formation by its broader pygidial axis with swollen posteroaxis and may be comparable to *A. sinensis* Peng, 1987. However, poor preservation of the specimens hinders its definite assignment to the species.

Order Corynexochida Kobayashi, 1935
Family Dorypygidae Kobayashi, 1935
Genus *Dorypyge* Dames, 1883

Type species: *Dorypyge richthofeni* Dames, 1883 from the Changhia Formation, Liaoning Province, China.

Remarks: Sundberg (1994) differentiated *Dorypyge* from *Kootenia* Walcott, 1889 and *Olenoides* Meek, 1877 by its subquadrate to medially inflated glabella, laterally thickening anterior pleural bands, and five to six pairs of equally long pygidial spines. *Dorypyge* has been widely reported from the middle Cambrian of Gondwana, Siberia, Laurentia, and Baltica (cf. Zhang and Jell, 1987).

Dorypyge richthofeni Dames, 1883
Figure 4(i)–(p)

Dorypyge richthofeni Dames, 1883, p. 24, pl. 1, figs. 1–6; Sun, 1924, p. 29, 30, pl. 2, figs. 3a–d; Kobayashi, 1937, p. 434, pl. 17, figs. 13a, b; Resser and Endo, 1937, p. 209, 210, pl. 31, figs. 14–18; Resser, 1942, p. 16; Kobayashi, 1960, p. 347, 348; Lu et al., 1962, p. 30, pl. 5, fig. 10; pl. 6, fig. 6; Lu et al., 1965, p. 97, 98, pl. 14, figs. 10, 11; Liu, 1982, p. 299, pl. 214, fig. 14; Zhang and Wang, 1985, p. 339, pl. 105, fig. 11; Zhang and Jell, 1987, p. 58, pl. 12, figs. 4–7; pl. 13, figs. 1–10; pl. 15, fig. 7; Zhu, 1992, p. 338, pl. 116, fig. 8; Guo et al., 1996, p. 93, 94, pl. 36, figs. 1–13; Luo, 2001, p. 337, p. 2, figs. 1–15; Peng et al., 2004a, p. 71, pl. 14, figs. 1–14; pl. 15, figs. 1–11; pl. 16, figs. 1–7a, 8–11; pl. 19, fig. 5.

Dorypyge richthofeni laevis Walcott, 1906, p. 573; Walcott, 1913, p. 109, pl. 8, figs. 2, 2', 2a; Kobayashi, 1960, p. 248, pl. 19, figs. 19–25.

Dorypyge damesi Resser and Endo, 1937, p. 209, pl. 31, figs. 14–18; Zhang and Jell, 1987, p. 59, 60, pl. 14, figs. 13–16.

Dorypyge laiwuensis Kobayashi, 1938, p. 887, fig. 1.

Dorypyge laevis (Walcott): Resser, 1942, p. 17; Zhang and Jell, 1987, p. 58, pl. 13, figs. 11–13; pl. 15, fig. 13.

Dorypyge lorenzi Resser, 1942, p. 18.

Dorypyge suni Resser, 1942, p. 19.

Dorypyge shantungensis Resser, 1942, p. 19.

Dorypyge chihliensis Resser, 1942, p. 19.

Dorypyge richthofeni chihliensis (Resser): Lu et al., 1965, p. 98, pl. 14, figs. 12, 13.

Dorypyge richthofeni damesi (Resser and Endo): Lu et al., 1965, p. 98, pl. 14, figs. 12, 13; Zhang, 1981, p. 155, pl. 59. fig. 5.

Dorypyge lata Zhang and Wang, 1985, p. 339, pl. 105, fig. 11.

Dorypyge zhaogeichuangensis Zhang and Wang, 1985, p. 339, pl. 105, fig. 12.

Dorypyge angusta Zhang and Wang, 1985, p. 339, pl. 106, fig. 13.

Material examined: One cranidium from DH2; three cranidia and five pygidia from DH4; and 29 cranidia and 23 pygidia from DH5.

Occurrence: *Crepicephalina* and *Amphoton* zones of the Daegi Formation, Korea; *Crepicephalina* Zone of North China; and *Dorypyge richthofeni* Zone of South China.

Remarks: The present cranidia are characterized by a strongly convex, subquadrate and medially inflated glabella, shallow lateral glabellar furrows, a very short preglabellar area, and variably impressed granules on the surface. The pygidia have three axial rings and a terminal piece and six pairs of marginal spines. Anterior four pairs of spines are equally long, the fifth pair is longer than others, and the sixth pair is very short. These specimens accord well with the description and illustration of *Dorypyge richthofeni* from China (cf. Zhang and Jell, 1987; Peng et al., 2004a). Kobayashi (1960) documented *Dorypyge richthofeni laevis* Walcott, 1913 from the Daegi Formation of Taebaek area. The subspecies was originally differentiated from *Dorypyge richthofeni* based on the smooth surface, but Zhang and Jell (1987) noted subdued granules on the glabella and fixed cheeks of the holotype cranidium. Re-examination of the material of Kobayashi (1960) also reveals that the cranidium, pygidia, and free cheeks possess fine granules. The materials from the Seokgaejae section also display a range of morphological variability in the size and density of granules: some have barely visible fine granules, while others possess large granules with sparse or dense distribution. Distinctiveness of glabellar furrows are also variable, ranging from no indication of glabellar furrows to clearly incised ones. Therefore, we concur with Zhang and Jell (1987) in that *Dorypyge richthofeni laevis* is a junior synonym of *Dorypyge richthofeni*.

Family Dolichometopidae Walcott, 1916
Genus *Amphoton* Lorenz, 1906

Type species: *Amphoton steinmanni* Lorenz, 1906 from the

Amphoton Zone, Changhia Formation, Shandong Province, China (synonymized with *Dolichometopus deois* Walcott, 1905 by Zhang and Jell, 1987).

Amphoton deois (Walcott, 1905)
Figure 5(a)–(d)

Dolichometopus deois Walcott, 1905, p. 94; Walcott, 1913, p. 216, pl. 21, figs. 13, 13a–d; pl. 22, figs. 1. 1a–h, 2, 2a, 2b.
Bathyuriscus asiaticus Lorenz, 1906, p. 87, pl. 5, figs. 1–5.
Amphoton steinmanni Lorenz, 1906, p. 89, pl. 4, figs. 15–17.
Amphoton deois (Walcott): Kobayashi, 1935, p. 138, pl. 22, fig. 12; Lu et al., 1965, p. 113, pl. 17, fig. 16; Zhang and Jell, 1987, p. 63, pl. 17, figs. 2–3, 5–14; pls. 18–20, 23; pl. 22, figs. 1–7; pl. 22, fig. 5; Peng et al., 2004a, p. 56, pl. 6, figs. 10–12. (for additional synonymy)
Amphoton parallela Resser and Endo, 1937, p. 206, pl. 38, figs. 2–8, 10–13; pl. 39, figs. 19, 20.
Amphoton alia Resser and Endo, 1937, p. 207, pl. 38, figs. 14–18.
Amphoton divergens Resser and Endo, 1937, (in part) p. 208, pl. 48, figs. 31, 32. (not fig. 33)
Dorypyge manchuriensis Resser and Endo, 1937, (in part) p. 208, pl. 31, fig. 3 only.
Amphoton blackwelderi Resser, 1942, p. 5.
Amphoton kaipingense Resser, 1942, p. 5.
Eurodeois deois (Walcott): Öpik, 1982, p. 58, pl. 20, fig. 5.
Amphotonella jingxianensis Guo et al., 1996, p. 98, pl. 38, figs. 9, 10; pl. 40, figs. 6–13.

Material examined: Two cranidia from DH4, and five cranidia and two pygidia from DH5 of the Daegi Formation, Seokgaejae section.

Occurrence: *Amphoton* Zone of the Daegi Formation, Korea; *Amphoton* Zone of North China; *Dorypyge richthofeni* Zone of South China; and *Ptychagnostus punctuosus* Zone of Australia.

Remarks: This species has been known from the *Ampho-*

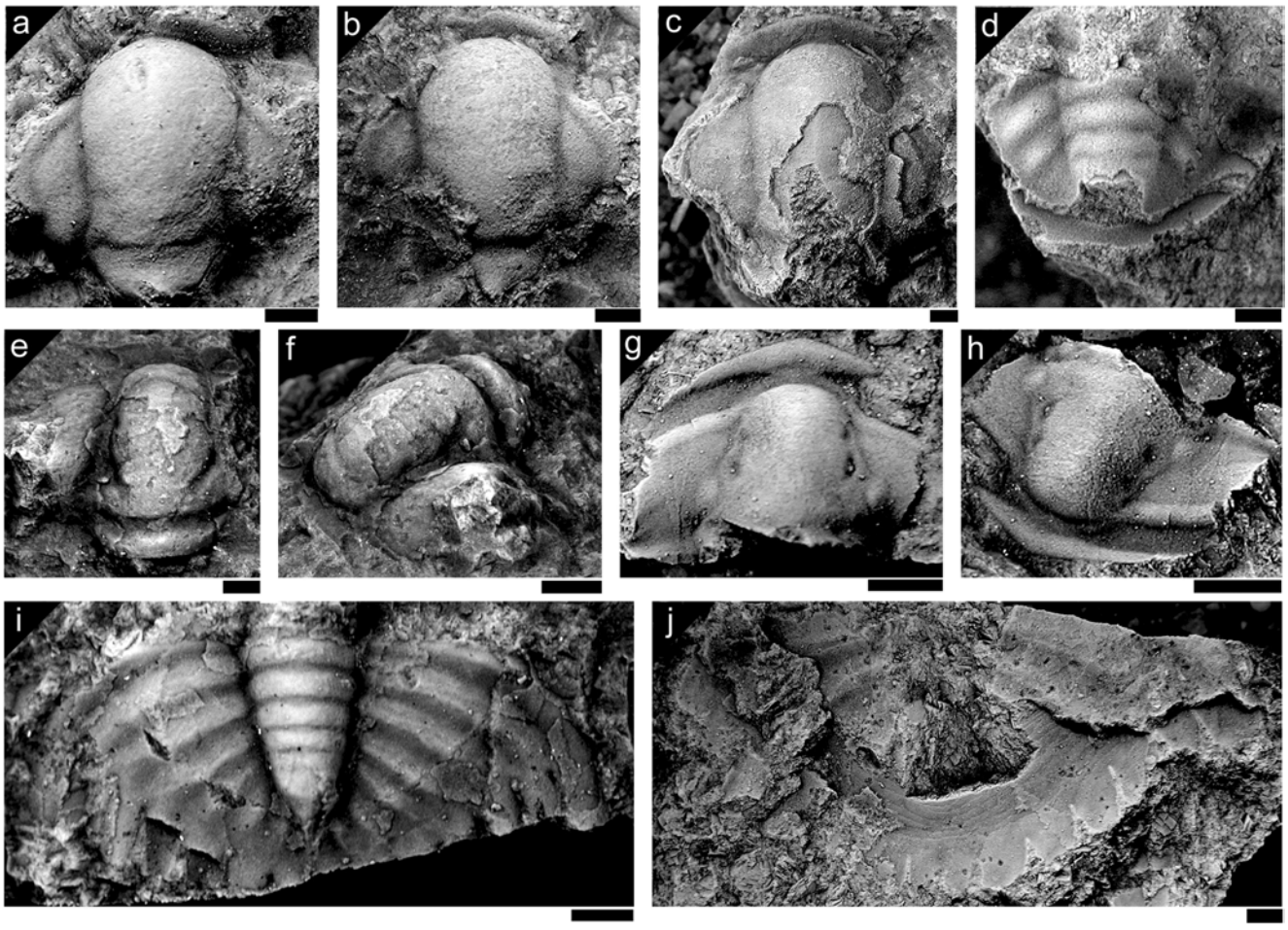

Fig. 5. Middle Cambrian trilobites from the Daegi Formation, the Seokgaejae section. Scale bars are 1mm long. (a)–(d) *Amphoton deois* (Walcott, 1905). (a) SNUP3517, testaceous cranidium, DH5. (b) SNUP3518, testaceous cranidium, DH4. (c) SNUP3519, partly exfoliated cranidium, DH5. (d) SNUP3520, partly exfoliated pygidium, DH5. (e)–(f) *Blackwelderia* sp. (e) SNUP3521, partly exfoliated cranidium, DH6. (f) oblique view of (e). (g)–(h) *Teinistion*? sp. (g) SNUP3522, testaceous cranidium, DH6. (h) oblique view of (g). (i)–(j) *Palaeadotes*? sp. (i) SNUP3523, exfoliated pygidium, DH6. (j) SNUP3524, exfoliated pygidium, DH6.

ton Zone of the Changhia Formation in Shandong and Liaoning provinces (Zhang and Jell, 1987, Guo et al, 1996), the *Dorypyge richthofeni* Zone of the Huaqiao Formation in Hunan Province (Peng et al., 2004a) of China, Chosan County of northern Korea (Kobayashi, 1935), and the *Ptychagnostus punctuosus* Zone of Australia (Öpik, 1982). This is the first record of *Amphoton* from the Taebaeksan Basin of Korea. The present specimens are poorly preserved, but show morphological features of *A. deois* provided by Zhang and Jell (1987).

Order Lichida Moore, 1959.
Family Damesellidae Kobayashi, 1935
Subfamily Damesellinae Kobayashi, 1935
Genus *Blackwelderia* Walcott, 1906

Type species: *Calymmene*? *sinensis* Bergeron (1889), North China.

Blackwelderia sp.
Figure 5(e)–(f)

Material examined: One cranidium from DH6 of the Daegi Formation, Seokgaejae section.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation.

Remarks: The cranidium shows the characteristic features of *Blackwelderia* in having a forward tapering glabella with distinct and concave S1. The fixed cheek is relatively narrow, occupying about one–half of glabellar width. This species is comparable to *Blackwelderia paronai* (Airaghi, 1902), but is described under open nomenclature due to poor preservation of preglabellar area.

Subfamily Dorypygellinae Kobayashi, 1935
Genus *Teinistion* Monke, 1903

Type species: *Teinistion lansi* Monke, 1903 from the *Blackwelderia* Zone, Kushan Formation, Shandong Province, China.

Teinistion? sp.
Figure 5(g)–(h)

Material examined: One cranidium from DH6 of the Daegi Formation, Seokgaejae section.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation.

Remarks: This specimen is incomplete, lacking palpebral lobes and most of posterior part. It may be comparable to *Teinistion* in glabellar structures such as pit–like lateral glabellar furrows, prominent eye ridges, and well-developed bacculae, but is unusual in having a subpentagonal cranidial outline and angulated anterior border. *Teinistion* has in general a subquadrate outline, abaxially widening preocular field, and transverse or concave anterior cranidial margin. Therefore this species is assigned to *Teinistion* with reservation.

Subfamily Drepanurinae Kobayashi, 1935
Genus *Palaeadotes* Öpik, 1967

Type species: *Palaeadotes dissidens* Öpik (1967, p. 341) from the *Glyptagnostus stolidotus* Zone, Georgina Basin, Queensland, Australia.

Remarks: The taxonomic position of *Palaeadotes* has been controversial owing to morphological similarity to *Drepanura* and *Bergeronites* (Zhang and Jell, 1987, Cooper et al., 1996). A comprehensive account on *Palaeadotes* has been recently made by Peng et al. (2004a, p. 130), which is followed in this study.

Palaeadotes? sp.
Figure 5(i)–(j)

Material examined: Three pygidia from DH6 of the Daegi Formation, Seokgaejae section.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation.

Remarks: The pygidia on hand are semicircular in outline and have a tapering axis, well-impressed pleural furrows, a wide doublure with 10–15 terrace lines, and seven pairs of marginal spines. The tips of spines are not preserved, but the anterior most spine is wider than other spines, implying that the most anterior spine would be the longest. Therefore these specimens are provisionally assigned to *Palaeadotes*.

Order Asaphida Salter, 1864
Family Anomocarellidae Hupé, 1953
Genus *Anomocarella* Walcott, 1905

Type species: *Anomocarella chinensis* Walcott, 1905 from the *Amphoton* Zone, Changhia Formation, Shandong Province, China.

Remarks: *Anomocarella* is characterized by a well-rounded glabella, flat to upturned anterior border, and semicircular pygidium. *Anomocarella* is closely similar to *Manchuriella* in cranidial morphology, but can be distinguished from the latter in possessing a more rounded glabella, eye ridges running from anterolateral glabellar corners, and an upturned anterior border with variably developed plectrum. *Anomocarella* has a semicircular pygidium with a long and narrow axis, whereas *Manchuriella* is characterized by a semielliptical pygidium with a short and wide axis.

Anomocarella temenus (Walcott, 1905)
Figure 6(a)–(d)

Anomocare temenus Walcott, 1905, p. 53; Walcott, 1913, p. 206, pl. 20, figs. 7, 7a–d.
Psilaspis temenus (Walcott): Resser and Endo, 1937, p. 270, pl. 37, figs. 1, 2.
Psilaspis manchuriensis Resser and Endo, 1937, p. 271, pl.

37, figs. 3–10.

Anomocarella temenus (Walcott): Lu et al., 1965, p. 324, pl. 60, figs. 1–4; Zhang and Jell, 1987, p. 183.

Anomocarella manchuriensis (Resser and Endo): Lu et al., 1965, p. 321, pl. 59, figs. 4–6.

Material examined: Three cranidia and four pygidia from DH2 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation, Korea; *Crepicephalina* Zone to *Amphoton* Zone of North China.

Remarks: *Anomocarella temenus* is characterized by its relatively wide glabella, anterior border without a plectrum, and wide doublure. Specimens from the Daegi Formation agree well with the description of *Anomocarella temenus* given by Zhang and Jell (1987), but have more convex pygidia.

Order Ptychopariida Kobayashi, 1935
Family Ptychopariidae Matthew, 1887

Ptychopariid gen. and sp. indeterminate.
Figure 6(e)–(f)

Material examined: Two cranidia from DH2 of the Daegi Formation, Seokgaejae section.

Description: Cranidium moderately convex, subquadrate in outline, 0.75 times as wide as long. Glabella cylindrical, moderately convex, ca. 0.3 and 0.6 of cranidial width and length, respectively. Axial furrows parallel–sided, narrow and moderately deep: preglabellar furrow broadly rounded to weakly acuminate. Lateral glabellar furrows obsolete. Occipital furrow transverse, straight, narrow and shallow. Occipital ring crescentic. Preglabellar field 0.1 of cranidial length, convex, sloping gently anteriorly and medially slightly depressed. Anterior border furrow narrow, moderately deep. Anterior border, short, convex, ridge-like. Eye-ridges very faint. Fixed cheeks as wide as glabella, gently sloping from palpebral lobes to axial furrows and anteriorly, and steeply sloping downward posteriorly. Palpebral lobes not preserved, but located behind glabellar mid-point.

Remarks: The specimens available are small (ca. 2 mm in cranidial width) and poorly preserved. Superficially they resemble *Liostracina* Monke, 1903, *Yuehsienzella* Zhang, 1957, and *Xilingxia* Lu *in* Zhang et al., 1980a reported from China. In particular, they are similar to the juvenile forms of *Yuehsienszella szechuanensis* (Zhang, 1957) from the upper lower Cambrian of South China (Zhang, 1957; Lu et al., 1963; Zhang, 1964; Luo, 1974; Zhou et al., 1977; Yin and Li, 1978; Zhang et al., 1980a; Zhang and Jell, 1987) in having a cylindrical glabella and very short anterior border. The specimen assigned to *Xilingxia ichangensis* (Zhang, 1964) from the *Dorypyge richthofeni* Zone (Taijiangian: middle Cambrian) of the Huaqiao Formation, Hunan, China (Peng et al., 2004b, pl. 1, figs. 15, 16) bears a morphological resemblance to the present material, but differs by its broader glabella and distinct median preglabellar furrow. *Liostracina* from the upper middle Cambrian of China, Korea and Australia (Monke, 1903; Walcott, 1913; Kobayashi, 1935; Resser and Endo, 1937; Zhu, 1960; Öpik, 1967; Zhang and Jell, 1987) is characterized by a median pregla-

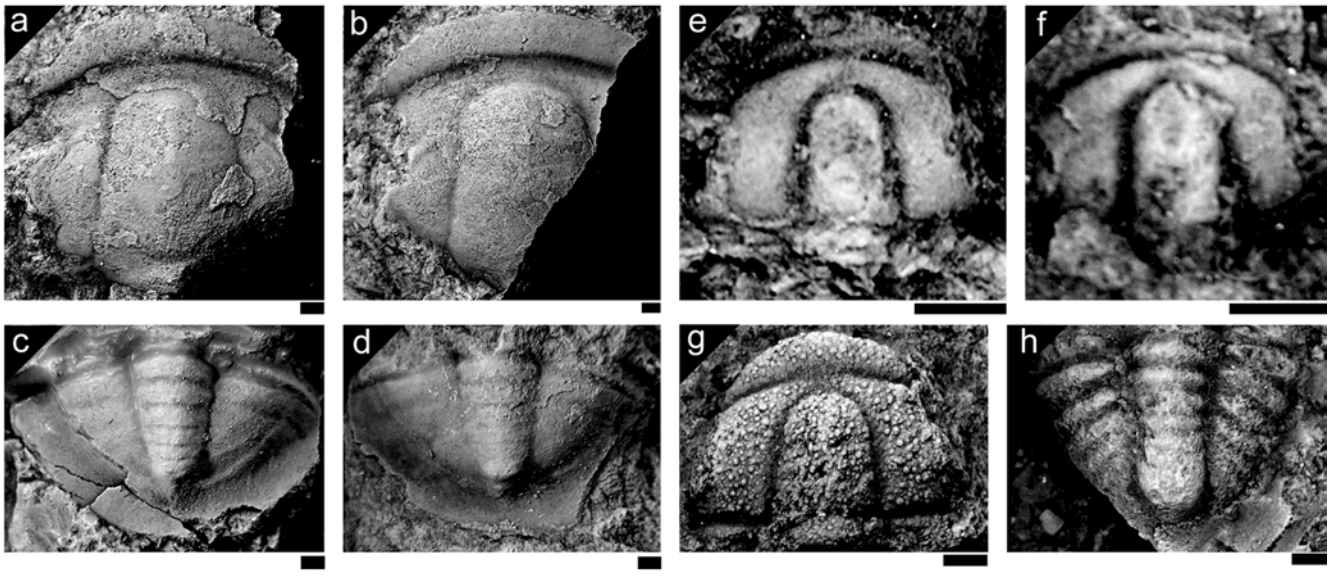

Fig. 6. Middle Cambrian trilobites from the Daegi Formation, the Seokgaejae section. Scale bars are 1mm long. (a)–(d) *Anomocarella temenus* (Walcott, 1905). (a) SNUP3525, mostly exfoliated cranidium, DH2. (b) SNUP3526, exfoliated cranidium, DH2. (c) SNUP3527, exfoliated pygidium, DH2. (d) SNUP3528, exfoliated pygidium, DH2. (e)–(f) ptychopariid gen. and sp. indeterminate. (e) SNUP3529, testaceous cranidium, DH2. (f) SNUP3530, testaceous cranidium, DH2. (g)–(h) *Changqingia deprati* (Kobayashi, 1935). (g) SNUP3531, testaceous cranidium, DH3. (h) SNUP3532, mostly exfoliated pygidium, DH1.

bellar furrow, distinct eye ridges, and bacculae, which are not observed in the present specimens. Because of insufficient number of specimens, these specimens are described under open nomenclature.

Family Solenopleuridae Angelin, 1854
Genus *Changqingia* Qiu et al., 1983

Type species: *Changqingia shandongensis* Qiu et al., 1983 from the *Crepicephalina* Zone, Changhia Formation, Liaoning Province, China.

Remarks: Qiu et al. (1983) erected *Changqingia* to differentiate from *Solenoparia* based on specimens from the Changhia Formation, Shandong, China. *Changqingia* is characterized by its wider, subquadrate to trapezoidal cranidium with forward-tapering glabella and depressed preglabellar field and a subtriangular pygidium with 6–10 axial rings. On the other hand, Zhang and Jell (1987) re-examined Walcott (1913)'s materials and transferred some species of *Solenoparia* to a new genus *Austrosinia*. Peng et al. (1995) however suppressed *Austrosinia* as a junior synonym of *Changqingia*.

Changqingia deprati (Kobayashi, 1935)
Figure 6(g)–(h)

Solenopleura (?) sp. Mansuy, 1916, p. 30, pl. 5, fig. 6.
Solenoparia (?) *deprati* Kobayashi, 1935, p. 266, pl. 19, figs. 3–6.
Austrosinia deprati (Kobayashi): Zhang and Jell, 1987, p. 92.

Material examined: One cranidium from DH3 and one pygidium from DH1 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation.

Remarks: The cranidium on hand is characterized by a long anterior border, medially depressed preglabellar field, and coarsely granulate sculpture. It is indistinguishable from the specimens assigned to *Solenoparia* (?) *deprati* Kobayashi, 1935, from the *Solenoparia* Zone of the Daegi Formation (Kobayashi, 1935). Zhang and Jell (1987) transferred *Solenoparia* (?) *deprati* to *Austrosinia.* As mentioned in the preceding, *Austrosinia* was treated to be a junior synonym of *Changqingia*, and hence this species is transferred to *Changqingia*. The pygidium from the Seokgaejae section, though poorly preserved, shows a resemblance to the pygidia assigned to *Solenoparia* (?) *deprati* by Kobayashi (1935) and is provisionally included in the species.

Family Crepicephalidae Kobayashi, 1935
Genus *Crepicephalina* Resser and Endo in Kobayashi, 1935

Type species: *Crepicephalus convexus* Walcott, 1911 from the *Crepicephalina* Zone, Changhia Formation, Liaoning Province, China.

Crepicephalina damia (Walcott, 1905)
Figure 7(a)–(l)

Crepicephalus damia Walcott, 1905, p. 92; Walcott, 1913, p. 141, pl. 13, figs. 14, 14a, b.
Ptychoparia vesta Walcott, 1906, p. 590.
Conokephalina vesta (Walcott): Walcott, 1913, (in part) p. 139, pl. 13, figs. 9 (not 9a–c).
Mesocrepicephalus damia (Walcott): Kobayashi, 1935, p. 277.
Aojia (?) *carinata* Resser and Endo, 1937, p. 177, pl. 48, fig. 21, 22.
Crepicephalina pergranosa Resser and Endo, 1937, p. 196, pl. 37, fig. 23; pl. 45, figs. 30, 31; pl. 46, figs. 18–21; Zhang and Jell, 1987, p. 83, pl. 36, figs. 5–9; pl. 37, figs. 1–11; pl. 38, figs. 1, 2; Guo et al., 1996, p. 100, pl. 45, figs. 1–6, 8, 9; Peng et al., 2004b, p. 69, pl. 68, fig. 11; Duan et al., 2005, p. 119. pl. 17, figs. 1–3.
Crepicephalina mukdensis Resser and Endo, 1937, p. 197, pl. 34, fig. 3; pl. 45, figs. 32–34.
Crepicephalina quadrata Resser and Endo, 1937, p. 197, pl. 46, figs. 22, 23; Zhang and Jell, 1987, p. 84, pl. 37, figs. 12, 13; Guo et al., 1996, p. 101, pl. 45, fig. 11.
Manchuriella mukdensis Resser and Endo, 1937, p. 245, pl. 36, fig. 22; Lu et al., 1965, p. 300, pl. 53, fig. 18.
Proasaphiscus kimurai Resser and Endo, 1937, p. 263, pl. 49, fig. 1.
Proasaphiscus (?) *mantouensis* Resser and Endo, 1937, (in part) p. 266, pl. 46, fig. 28. (not pl. 46, fig. 29)
Proasaphiscus (?) *willisi* Resser and Endo, 1937, p. 267, pl. 46, fig. 27; Lu et al., 1965, p. 289, pl. 50, fig. 18.
Proasaphiscus offula Resser and Endo, 1937, p. 267, pl. 46, fig. 30.
Crepicephalina damia (Walcott): Lu, 1957, p. 269, pl. 141, figs. 24, 25; Zhang and Jell, 1987, p. 82, pl. 36, figs. 1–3; Guo et al., 1996, p. 99, pl. 44, figs. 1–6; pl. 45, figs. 7, 10; Duan et al., 2005, p. 118. pl. 17, figs. 6–9.
Szeaspis (?) *offula* (Resser and Endo): Zhang, 1959, p. 208.
Crepicephalina damia var. *rectangula*; Zhang, 1959, p. 232, pl. 4, figs. 3, 4; Duan et al., 2005, p. 118. pl. 16, figs. 18–20.
Crepicephalina angustigenata Qiu et al., 1983, p. 89, pl. 29, figs. 7, 8.
Crepicephalina danazhuangensis Qiu et al., 1983, p. 89, pl. 30, fig. 6.
Crepicephalina vesta (Walcott): Zhang and Jell, 1987, p. 84, pl. 36, fig. 4.
Crepicephalina carinata (Resser and Endo): Zhang and Jell, 1987, p. 84, pl. 38, fig. 3.
Crepicephalina offula (Resser and Endo): Zhang and Jell, 1987, p. 85, pl. 65, fig. 13.
Crepicephalina elongata Guo et al., 1996, p. 101, pl. 44, figs. 7–9.
Crepicephalina convexus (Walcott, 1905): Luo, 2001, p. 377, pl. 1, figs. 5–8.

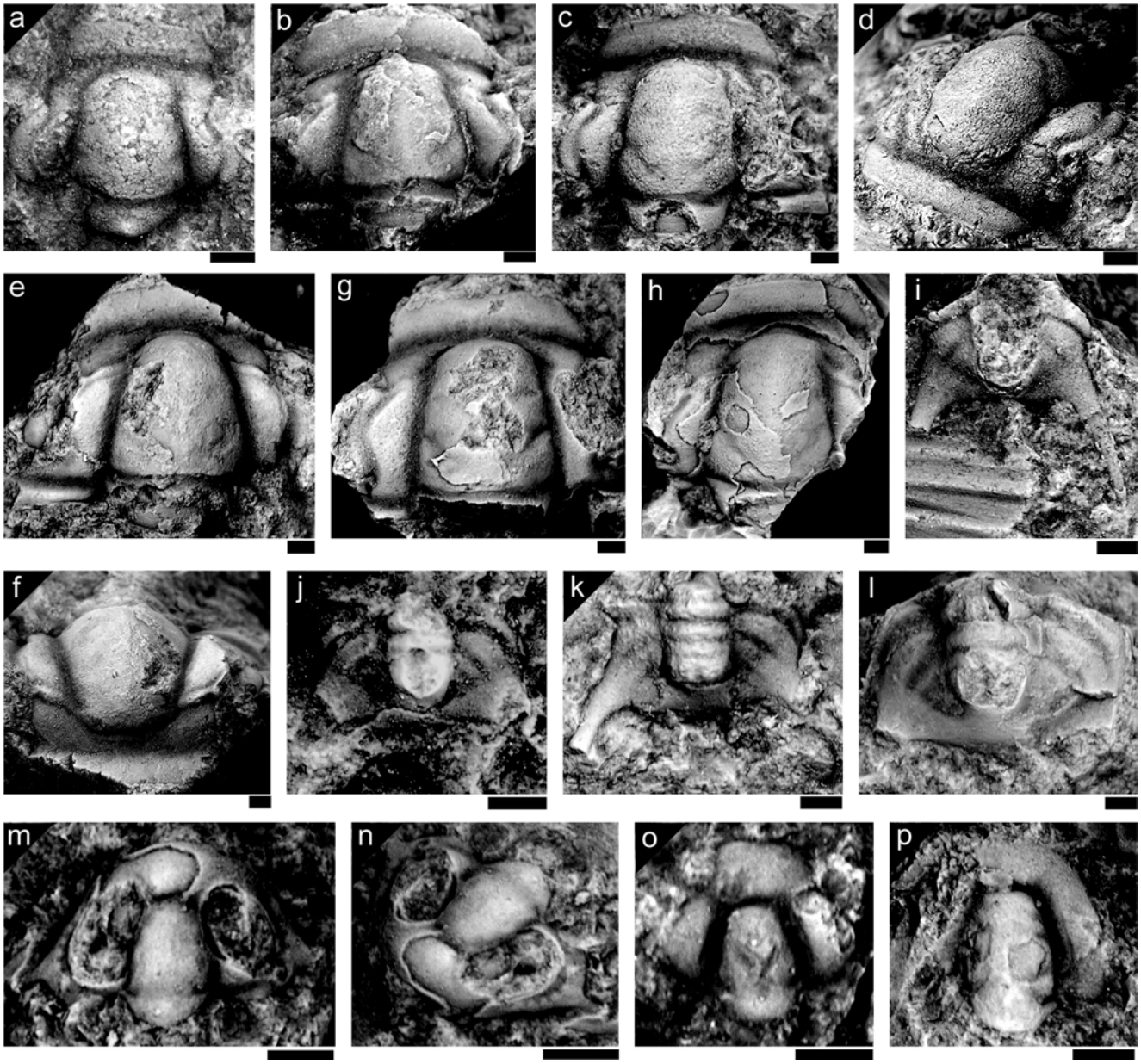

Fig. 7. Middle Cambrian trilobites from the Daegi Formation, the Seokgaejae section. Scale bars are 1mm long. (a)–(l) *Crepicephalina damia* (Walcott, 1905). (a) SNUP3533, testaceous cranidium, DH2. (b) SNUP3534, partly exfoliated cranidium, DH2. (c) SNUP3535, testaceous cranidium, DH2. (d) oblique view of (c). (e) SNUP3536, exfoliated cranidium, DH2. (f) anterior view of (e). (g) SNUP3537, mostly exfoliated cranidium, DH2. (h) SNUP3538, partly exfoliated cranidium, DH2. (i) SNUP3539, testaceous pygidium, DH2. (j) SNUP3540, testaceous pygidium, DH2. (k) SNUP3541, mostly exfoliated pygidium, DH2. (l) SNUP3542, testaceous pygidium, DH2. (m)–(o) *Cyclolorenzella rotundata* (Resser and Endo, 1937). (m) SNUP3543, mostly exfoliated cranidium, DH6. (n) anterior view of (m). (o) SNUP3544, exfoliated cranidium, DH6. (p) *Cyclolorenzella* sp. SNUP3545, exfoliated cranidium, DH6.

Material examined: Sixty-seven cranidia and eight pygidia from DH2 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation; *Crepicephalina* Zone of North China; and *Dorypyge richthofeni* Zone of South China.

Remarks: Cranidia assigned to *Crepicephalina damia* from the Daegi Formation exhibit a broad range of morphological variability in size and morphology. They range from less than 3 mm to ca. 12 mm in cranidial length. Morphological variations are particularly evident in the relative length of palpebral lobes, preglabellar field, and anterior border: the smaller specimens have relatively longer palpebral lobes than the large ones. However, as Zhang and Jell (1987) noted, the difference in the cranidia is too subtle to be employed to differentiate the species. Thus, it is recommended that species of *Crepicephalina* be identified mainly by pygidial morphology until the taxonomic problem is resolved.

While allowing the intraspecific variations observed above, many of the Chinese species can be synonymized. Zhang and Jell (1987) regarded *C. carinata* as an exfoliated form of *C. pergranosa* and also suspected that the smaller forms (e.g., *C. vesta*, *C. quadrata*, and *C. offula*) may possibly represent the juvenile stages of *C. pergranosa*. In addition, the type material of *Crepicephalina pergranosa* (illustrated by Zhang and Jell, 1987) cannot be objectively differentiated from *C. damia*, and hence the two species are synonymized. *Crepicephalina angustigenata* Qiu et al., 1983 and *C. dananzhuangensis* Qiu et al., 1983 are also considered to be junior synonyms of *C. damia*.

Crepicephalina damia is distinguished from the type species, *C. convexa*, mainly in pygidial morphology comprising a narrower and more segmented axis, longer and stouter pygidial spines, and abaxially posteriorly curved pleural furrows, which are distinct from strongly posteriorly directed pleural furrows in the lectotype pygidium of *C. convexa* (Walcott, 1913, pl. 13, fig. 16b; refigured by Zhang and Jell, 1987, pl. 35. figs. 10–11).

Family Diceratocephalidae Lu, 1954
Genus *Cyclolorenzella* Kobayashi, 1960

Type species: *Lorenzella quadrata* Kobayashi, 1935 from the *Drepanura* Zone (upper middle Cambrian), Sesong Formation, Korea.

Remarks: Kobayashi (1960) erected *Cyclolorenzella* based on *Lorenzella quadrata* Kobayashi, 1935 from the *Drepanura* Zone of Korea, and transferred some of the species previously assigned to *Agraulos* and *Lorenzella* to the genus. Zhang and Jell (1987) attempted to differentiate *Cyclolorenzella* from *Aulacodigma*, *Fenghuangella*, and *Torifera*: *Aulacodigma* is characterized by its transverse subtrapezoidal cranidium with a relatively long preglabellar field; *Fenghuangella* by a conical glabellar front; and *Torifera* by the presence of short anterior cranidial border and border furrow. Moreover, *Torifera* has more anteriorly located palpebral lobes than *Cyclolorenzella* (cf. Peng et al., 2004b). *Cyclolorenzella* sp. from England (Rushton, 1978) should be referred to *Torifera*, though the specimen does not preserve the anterior border. *Cyclolorenzella* sp. from Kashmir (Jell, 1986) also should be transferred to *Torifera*, as it was described to have an anterior border. Accordingly the occurrence of *Cyclolorenzella* is confined to upper middle Cambrian of North China and Korea.

Cyclolorenzella rotundata (Resser and Endo, 1937)
Figure 7(m)–(o)

Lorenzella rotundata Resser and Endo, 1937, p. 232, pl. 46, figs. 4–6.
Lorenzella parabola Lu, 1957, p. 272, pl. 142, fig. 14; Zhu, 1959, p. 59, pl. 1, fig. 1; pl.2, figs. 1–5.
Cyclolorenzella parabola (Lu): Kobayashi, 1960, p. 389; Guo et al., 1996, p. 114, pl. 53, figs. 1–16.
Cyclolorenzella rotundata (Resser and Endo): Kobayashi, 1960, p. 389; Lu et al., 1965, p. 253, figs. 5–7.
Cyclolorenzella acalle (Walcott): Zhang and Jell, 1987, (in part) p. 132, pl. 51, figs. 5–7 (not figs. 1–4).

Material examined: Thirteen cranidia from DH6 of the Daegi Formation, Seokgaejae section.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation; *Blackwelderia* Zone of North China.

Remarks: *Cyclolorenzella rotundata* is easily distinguished from other species of *Cyclolorenzella* by its strongly convex preglabellar field which is separated from convex fixigenae by a pair of divergent and deep furrows emerging from anterolateral corners of glabella. One of the specimens (Figs. 7m–n) retains narrow free cheeks with short genal spines. *Cyclolorenzella parabola* (Lu, 1957) is closely similar to *C. rotundata* in having the diverging furrows on frontal area, and thus is synonymized with *C. rotundata*. *Cyclolorenzella convexa* has comparable furrows, which however run forwards from anterolateral glabellar corners.

Cyclolorenzella sp.
Figure 7(p)

Material examined: Three cranidia from DH6 of the Daegi Formation, Seokgaejae section.

Occurrence: *Cyclolorenzella* Zone of the Daegi Formation.

Remarks: These specimens lack deep furrows on frontal area and certainly do not belong to *C. rotundata*. Their poor preservation, however, precludes assignment to the species level.

Family Proasaphiscidae Zhang, 1963
Genus *Proasaphiscus* Resser and Endo in Kobayashi, 1935

Type species: *Proasaphiscus yabei* Resser and Endo in Kobayashi, 1935 from the *Bailiella* Zone, Hsuchuang Formation, Liaoning Province, China.

Proasaphiscus sp.
Figure 8(a)–(c)

Material examined: Three cranidia and seven pygidia from DH1 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation.

Remarks: *Proasaphiscus* sp. has a long and rectangular glabella and a long, flat, and downsloping anterior border. The accompanying pygidia are characterized by a semicircular outline, indistinct border furrow, broad doublure, and strongly posteriorly directed pleural furrows, which are diagnostic features of *Proasaphiscus*. The present material may be comparable to *Proasaphiscus tschanghsingensis* Resser and Endo, 1937 in having a relatively long preglabellar

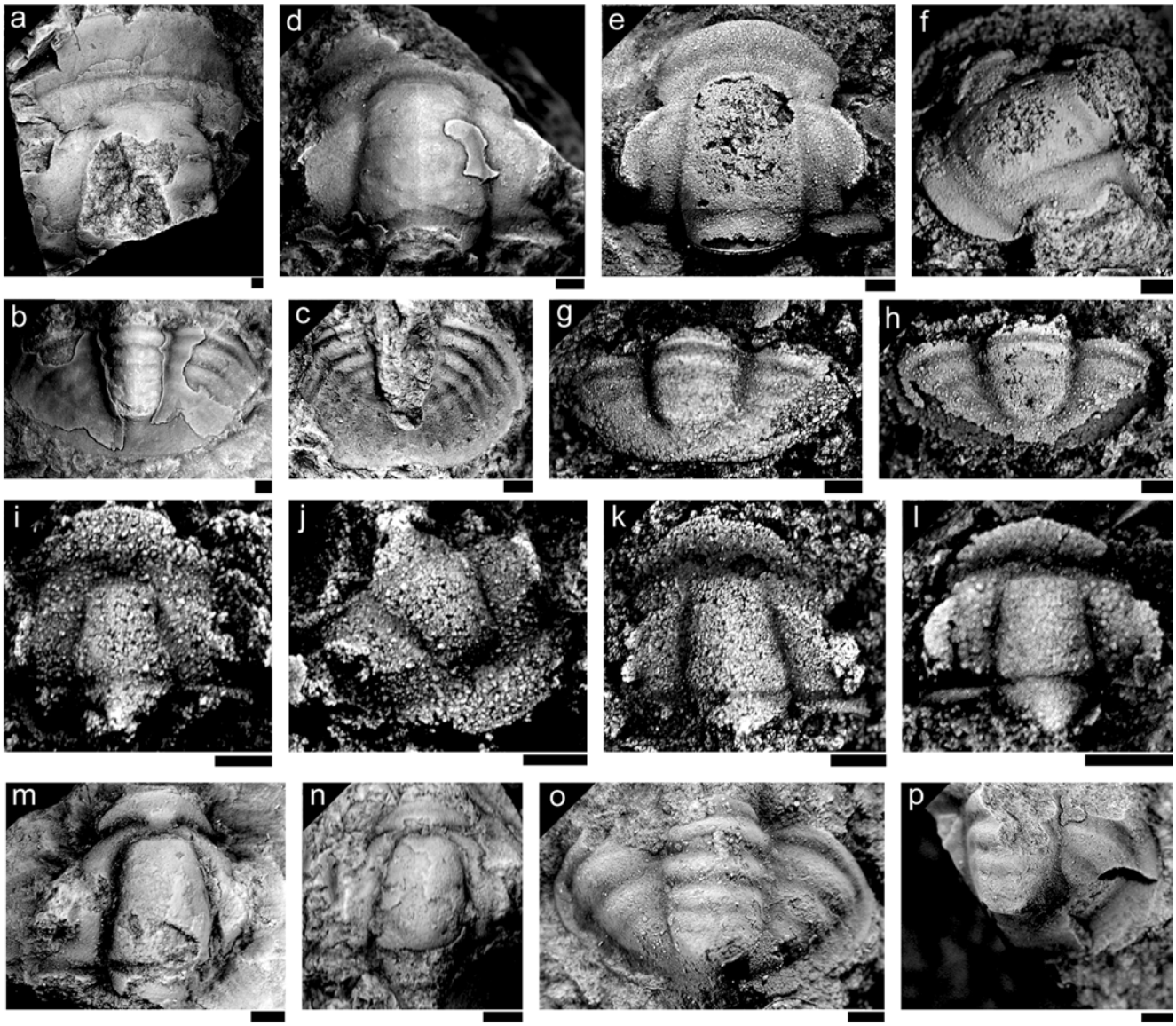

Fig. 8. Middle Cambrian trilobites from the Daegi Formation, the Seokgaejae section. Scale bars are 1mm long. (a)–(c) *Proasaphiscus* sp. (a) SNUP3546, exfoliated cranidium, DH1. (b) SNUP3547, partly exfoliated pygidium, DH1. (c) SNUP3548, exfoliated pygidium, DH1. (d)–(h) *Manchuriella macar* (Walcott, 1911). (d) SNUP3549, mostly exfoliated cranidium, DH1. (e) SNUP3550, testaceous cranidium, DH3. (f) oblique view of (e). (g) SNUP3551, testaceous pygidium, DH3. (h) SNUP3552, testaceous pygidium, DH3. (i)–(l) *Ignotogregatus* sp. cf. *I. manholi* Zhang and Jell, 1987. (i) SNUP3553, testaceous cranidium, DH3. (j) oblique view of (i). (k) SNUP3554, testaceous cranidium, DH3. (l) SNUP3555, testaceous cranidium, DH3. (m)–(p) *Metanomocarella tumida* (Resser and Endo, 1937). (m) SNUP3556, mostly exfoliated cranidium, DH1. (n) SNUP3557, partly exfoliated cranidium, DH1. (o) SNUP3558, testaceous pygidium, DH2. (p) SNUP3559, partly exfoliated pygidium, DH2.

field, flat, downsloping anterior border, and weak indentation on posterior margin of pygidium.

Genus *Manchuriella* Resser and Endo in Kobayashi, 1935

Type species: *Manchuriella typa* Resser and Endo in Kobayashi, 1935 from the *Crepicephalina* Zone, Changhia Formation, Liaoning Province, North China.

Remarks: Zhang and Jell (1987) discussed that the pygidia of *Manchuriella* had been wrongly matched and provided emended diagnosis for the genus. *Manchuriella* mainly differs from *Proasaphiscus* in having a transversely semielliptical pygidium with fewer axial rings. The cranidium of *Manchuriella* can be only distinguished from that of *Proasaphiscus* by its more rounded glabellar front and shorter preglabellar field.

Manchuriella macar (Walcott, 1911)
Figure 8(d)–(h)

Anomocarella macar Walcott, 1911, (in part) p. 92, pl. 15, figs. 11, 11a (not fig. 11b); Walcott, 1913, (in part) p. 203, pl. 20, figs. 6, 6a (not figs. 6b–d).

Manchuriella macar (Walcott): Resser and Endo, 1937, (in part) p. 245, pl. 36, figs. 16, 18 (not figs. 17, 19–21); Lu et al., 1965, (in part) p. 300, pl. 54, figs. 1, 2 (not figs. 3, 4); Zhang and Jell, 1987, (in part) p. 151, pl. 60, figs. 13, 14; pl. 61, figs. 5, 10, 14, 16; pl. 62, figs. 3, 5–7, 9, 10, 11, (not pl.61 figs. 1–3, 6–9, 11–13, 15; pl. 62, 1, 2, 4, 8; pl. 63, fig. 7).

Material examined: Two cranidia and two pygidia from DH1 and 51 cranidia and 23 pygidia from DH3 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation; *Crepicephalina* Zone of North China (Zhang and Jell, 1987).

Remarks: Zhang and Jell (1987) synonymized several species of *Manchuriella*, including *Manchuriella macar*, with *M. typa*. However, *Manchuriella macar* can be distinguished from *M. typa* in having relatively large palpebral lobes and a short preglabellar field, and thus *M. macar* is restored in this study.

Family Ignotogregatidae Zhang and Jell, 1987

Genus *Ignotogregatus* Zhang and Jell, 1987

Type species: *Ignotogregatus manholi* Zhang and Jell, 1987 from the *Crepicephalina* Zone, Changhia Formation, Liaoning Province, China.

Ignotogregatus sp. cf. *I. manholi* Zhang and Jell, 1987
Figure 8(i)–(l)

cf. *Ignotogregatus manholi* Zhang and Jell, 1987, p. 172, pl. 68, figs. 10–12, pl. 69, figs. 1–7.

Material examined: Thirty-five cranidia from DH3 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation.

Remarks: The specimens available are poorly preserved and small, ranging from 2 to 4 mm in cranidial width, and are characterized by a trapezoidal glabella, steeply downsloping preglabellar area, and kidney–shaped upturned palpebral lobes. In these respects, they are closely comparable to *Ignotogregatus manholi* by Zhang and Jell, 1987. The Chinese specimens display a prominent plectrum and granulate ornamentation. Meanwhile the specimens from the Daegi Formation have a less developed plectrum or effaced surface, and a prominent occipital spine. Therefore, the present material is assigned to *Ignotogregatus manholi* with reservation.

Family Mapaniidae Zhang, 1963

Genus *Metanomocarella* Zhang, 1959

Type species: *Metanomocarella rectangula* Zhang, 1959 from the *Crepicephalina* Zone, Changhia Formation, Shandong Province, China.

Remarks: *Metanomocarella* was erected to accommodate some of the species assigned to *Anomocarella* which have an oblong glabella, convex and tumid anterior border, narrow and convex cheek, deep glabellar furrows, and a pygidium without lateral spines (Zhang, 1959). It was also suggested that *Metanomocarella* is different from *Aojia* in having an oblong glabella, tumid border, no occipital spine and pygidium without lateral spines (Zhang, 1959).

Metanomocarella tumida (Resser and Endo, 1937)
Figure 9(m)–(p)

Aojia tumida Resser and Endo, 1937, p. 175, pl. 47, figs. 6, 7; Endo, 1944, p. 65, pl. 1. figs. 15, 16; pl. 2, figs. 1–4.

Anomocarella tumida (Resser and Endo): Endo, 1944, p. 86, pl. 2, figs. 10–15.

Metanomocarella tumida (Resser and Endo): Lu et al., 1965, p. 337, pl. 62, figs. 26, 27; Zhang and Jell, 1987, p. 190, pl. 79, figs. 9, 10; Guo et al., 1996, p. 89, pl. 65, figs. 6, 7.

Material examined: Six cranidia and four pygidia from DH1 and DH2 of the Daegi Formation, Seokgaejae section.

Occurrence: *Crepicephalina* Zone of the Daegi Formation; *Crepicephalina* Zone of North China.

Remarks: *Metanomocarella tumida* is characterized by a forward-tapering glabella, faint lateral glabellar furrows, a short preglabellar field, a tumid anterior border with a plectrum, narrow fixed cheeks, a semicircular pygidium, and a pygidial axis with four axial rings and a terminal piece. The specimens from the Daegi Formation correspond well with those of *Metanomocarella tumida* from North China (Zhang and Jell, 1987; Guo et al., 1996).

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