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Original article

Upper Cambrian polymerid trilobites from the Machari Formation, Yongwol, Korea

Trilobites polyméridés du Cambrien supérieur de la formation Machari, Yongwol, Corée

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Abstract

This article deals with the systematic description of polymerid trilobites from the Upper Cambrian *Eochuangia hana*, *Agnostotes orientalis*, and *Pseudoyuepingia asaphoides* Zones of the Machari Formation, Konggiri section, Yongwol, Korea. Agnostoid trilobites from the same locality were reported in 2004. Described are 20 polymerid trilobite taxa, including two new genera (*Joshuaspis* and *Macharia*) and four new species (*Metachangshania brachypyga*, *Proceratopyge promisca*, *Joshuaspis parvus*, and *Macharia pengi*). While agnostoid trilobite assemblages were used for correlation with distant regions such as South China, Australia, Kazakhstan, Siberia, and Laurentia, these polymerid trilobite assemblages provide valuable information for correlation of the Machari Formation with the Furongian (Upper Cambrian) strata of North China.

Résumé

Cet article présente une description systématique des trilobites polyméridés de la zone à *Eochuangia hana*, *Agnostotes orientalis* et *Pseudoyuepingia asaphoides* du Cambrien supérieur de la formation Machari, coupe de Yongwol, Corée. Les trilobites agnostidés de la même localité ont été décrits en 2004. Vingt taxons de trilobites polyméridés dont deux nouveaux genres (*Joshuaspis* et *Macharia*) et quatre nouvelles espèces (*Metachangshania brachypyga*, *Proceratopyge promisca*, *Joshuaspis parvus* et *Macharia pengi*) sont décrits. Alors que les assemblages de trolobites agnostidés étaient utilisés pour des corrélations avec des régions éloignées comme la Chine, l'Australie, le Kazakhstan, la Sibérie et Laurentia, ces trilobites polyméridés fournissent des informations précieuses pour une corrélation de la formation Machari avec les strates du Furongien (Cambrien supérieur) de la Chine du nord.

Keywords: Late Cambrian; Polymerid trilobites; Korea; Biostratigraphy

Mots clés : Cambrien supérieur ; Trilobites polyméridés ; Corée ; Biostratigraphy

1. Introduction

The Machari Formation in Korea is well known for yielding abundant and diverse Cambrian invertebrate fossils, which were referred to the Machari fauna (Kobayashi, 1962). Trilobites of the Machari fauna have been intensively studied during the last decade (Lee and Choi, 1994, 1995, 1996, 1997, 1999; Choi and Lee, 1995; Lee et al., 2001; Hong et al., 2003a, 2003b; Choi et al., 2004; Hwang and Choi, 2005). Recently Choi and Chough (2005) compiled the lithostratigraphy and biostratigraphy of the Cambrian-Ordovician Choson Supergroup, in which the up-to-date biostratigraphy of the Machari Formation is summarized. These biostratigraphic zones of the Machari Formation are in ascending order the *Tonkinella*, *Lejopyge armata*, *Glyptagnostus stolidotus*, *Glyptagnostus reticulatus*, *Proceratopyge tenuis*, *Hancrania brevilimbata*, *Eugonocare longifrons*, *Eochuangia*

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hana, *Agnostotes orientalis* and *Pseudoyuepingia asaphoides* Zones. Most of trilobites from these zones were already reported in publications cited above.

Of these, the uppermost three zones, *E. hana*, *A. orientalis*, and *P. asaphoides* Zones, yield very abundant and diverse trilobite assemblages of Furongian (Upper Cambrian) age. Choi et al. (2004) described 24 species of agnostoid trilobites recovered from the three zones of the Konggiri section, while mentioning the need for further exhaustive taxonomic treatment for associated polymerid trilobites. Some polymerids from the section were published elsewhere (Lee et al., 2001; Hong et al., 2003b; Choi and Kim, 2006). This article primarily deals with the systematic description of polymerid trilobites from the *E. hana*, *A. orientalis*, and *P. asaphoides* Zones of the Konggiri section, and attempts to complete the systematic study of the Furongian trilobites of the Machari Formation. The reader is referred to Choi et al. (2004) for detailed information on general geology, location, and stratigraphic correlation of the Konggiri section.

2. Supplementary notes on biostratigraphy

The Konggiri section (128° 26' 29'' E and 37° 18' 42'' N) is located at a hillside near Konggiri village, Yongwol (Choi et al., 2004: Fig. 1) and comprises the *E. hana*, *A. orientalis*, and *P. asaphoides* Zones of middle Furongian age. A total of 24 agnostoid species belonging to 13 genera were known to occur in the section (Choi et al., 2004); this study reports 20 polymerid taxa belonging to 14 genera. The stratigraphic occurrences of polymerid trilobites in the Konggiri section are shown in Fig. 1 and refined correlation of these zones with other parts of the world is given in Fig. 2.

2.1. Eochuangia hana *Zone*

The *E. hana* Zone was known to yield 12 agnostoid species (Choi et al., 2004). Twelve polymerid trilobite taxa are added to the faunal list of the zone: *Irvingella megalops* (Kobayashi, 1962), *Proceratopyge promisca* nov. sp., *Pseudeugonocare bispinatum* (Kobayashi, 1962), *Macharia pengi* nov. sp., *Joshuaspis parvus* nov. sp., *Irvingella convexa* (Kobayashi, 1935), *Chuangia* spp., *Dikelocephalites flabelliformis* Sun, 1935, *Haniwoides longus* Kobayashi, 1935, *E. hana* Kobayashi, 1935, *Changshania equalis* Sun, 1935, and *Metachangshania brachypyga* nov. sp. Among them, stratigraphically important taxa are *I. megalops*, *I. convexa*, *E. hana*, and *C. equalis*.

Changshania has hitherto been known to occur exclusively in North China (Choi and Kim, 2006). The *Changshania conica* Zone was formally established from the Changshan Formation of Hebei province by Sun (1935), and later Lu and Dong (1953) confirmed the *Changshania* Zone in the Tangwangzhai section of Shandong province, China. Lu and Qian (1983) proposed the *C. conica–Irvingella taitzuhoensis* Zone based on the occurrence of *Irvingella* in the *Changshania* Zone in Liaoning province. The association of *Changshania* and *Irvingella* is very significant for biostratigraphic correlation of the Sino-Korean block with other parts of the world, as *Irvingella* is a cosmopolitan trilobite with a relatively short stratigraphic range within the Furongian (Hong et al., 2003b). In the Konggiri section, *C. equalis* is associated with *I. convexa* in the uppermost interval of the *E. hana* Zone (Fig. 1). The successive occurrence of four species of *Irvingella* has been documented in the section (Hong et al., 2003b): *I. megalops* and *I. convexa* occur in the lower and upper parts of the *E. hana* Zone, whereas *I. coreanica* Hong et al., 2003b and *I. major* Ulrich and Resser in Walcott, 1924 occupy the lower and upper parts of the *A. orientalis* Zone respectively (Fig. 1).

Recently the association of *Changshania* and *Irvingella* has been frequently recorded in North China (Lu and Qian, 1983; Guo and Zhang, 1992; Qian, 1994; Zhang et al., 1995). The associated *Irvingella* species were identified as either *I. taitzuhoensis* Lu, 1957 or *I. flohri* Resser, 1942. According to Hong et al. (2003b), both *I. taitzuhoensis* and *I. flohri* occur stratigraphically lower than *I. major* and are comparable to *I. convexa* in terms of morphological development in the *Irvingella* lineage. This interpretation is also consistent with the stratigraphic occurrences of *Irvingella* in North China: that is, *I. taitzuhoensis* and *I. flohri* were recovered from the *Changshania–Irvingella* Zone (Lu and Qian, 1983; Guo and Zhang, 1992; Qian, 1994), while *I. major* from the superjacent *Maladioidella* Zone in Liaoning province (Guo and Zhang, 1992). It is of noteworthy that Guo and Zhang (1992) established the *Eochuangia* Zone, based on the occurrence of *E. hana* in Liaoning province, which occupies the interval between the *Changshania* and *Maladioidella* Zones in the Liaodong Peninsula. Qian (1994) reported the presence of *Eochuangia* in the *Changshania–Irvingella* Zone of Nei Mongol.

2.2. Agnostotes orientalis *Zone*

The *A. orientalis* Zone comprises 12 agnostoid trilobites (Choi et al., 2004). The polymerid trilobites include six species: *P. promisca* nov. sp., *Pseudeugonocare bispinatum*, *Chuangia* spp., *Haniwoides longus*, *I. coreanica*, and *I. major*. The age-diagnostic taxa are *A. orientalis* (Kobayashi, 1935), *I. coreanica*, and *I. major* (Fig. 1).

The *A. orientalis* Zone should be contemporaneous with the *Maladioidella* Zone of North China, as both zones yield *Irvingella major*. The correlation of these zones outside the Sino-Korean block can be achieved by tracing the occurrences of *Irvingella* and *Agnostotes* (Fig. 2). The association of *Irvingella* and *Agnostotes* has been documented in the *A. clavatus–Irvingella angustilimbata* Zone of South China (Peng, 1992) and the *Irvingella tropica* Zone of Australia (Öpik, 1963; Shergold, 1982). The occurrence of the youngest species of *Irvingella*, *I. major*, makes it possible to correlate the *A. orientalis* Zone with the *I. major* Zone of Laurentia (Palmer, 1965; Pratt, 1992). The taxonomy and stratigraphic significance of *A. orientalis* has been thoroughly treated by Peng and Babcock (2005).

2.3. Pseudoyuepingia asaphoides *Zone*

The *P. asaphoides* Zone is comparatively less diverse than the lower two zones in yielding eight agnostoid (Choi et al.,

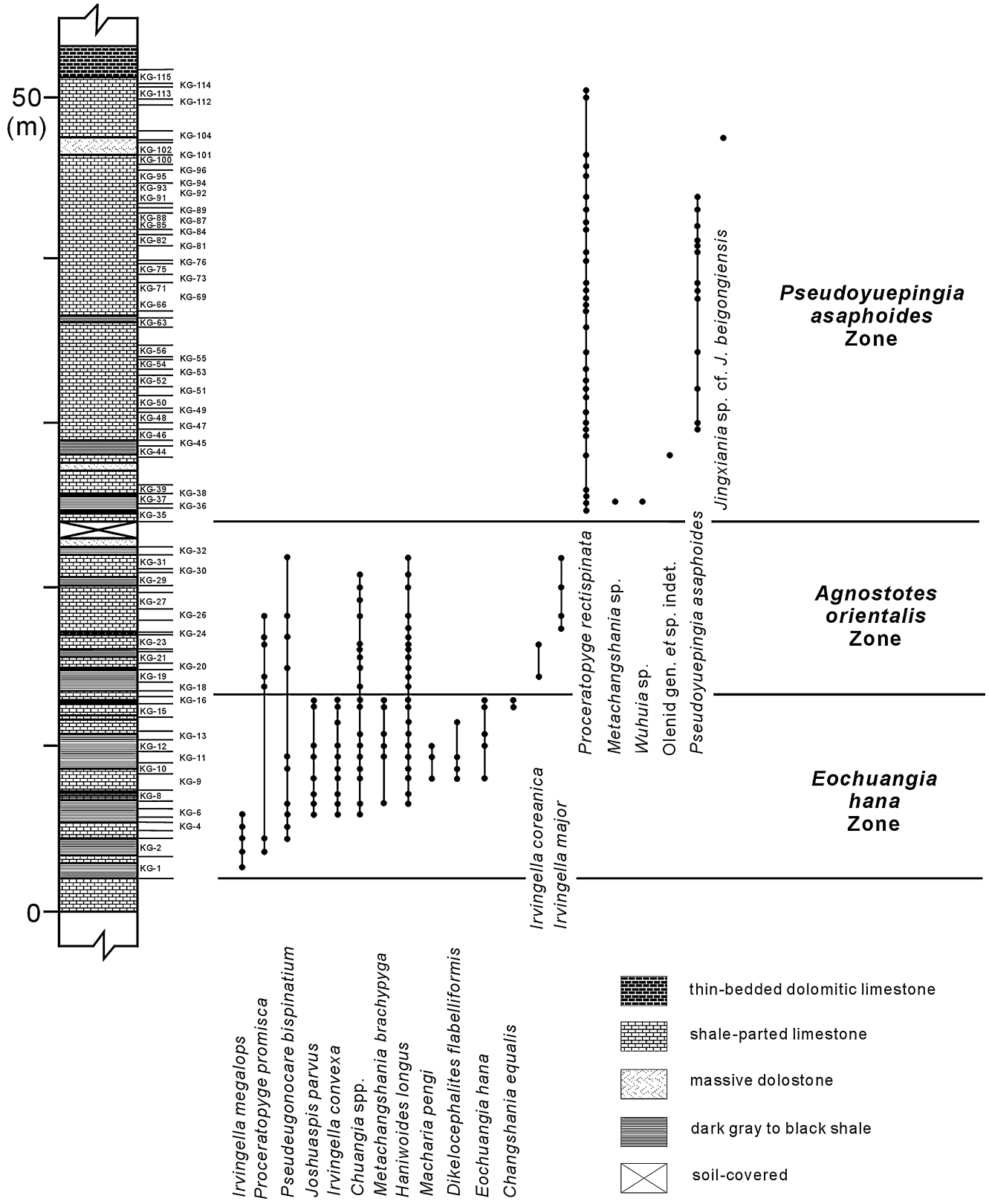

Fig. 1. Generalized lithologic column of the Machari Formation at the Konggiri section with occurrence of polymerid trilobites and stratigraphic distribution of the biozones. Numbers with prefix KG represent the sampling units from which trilobites were collected.

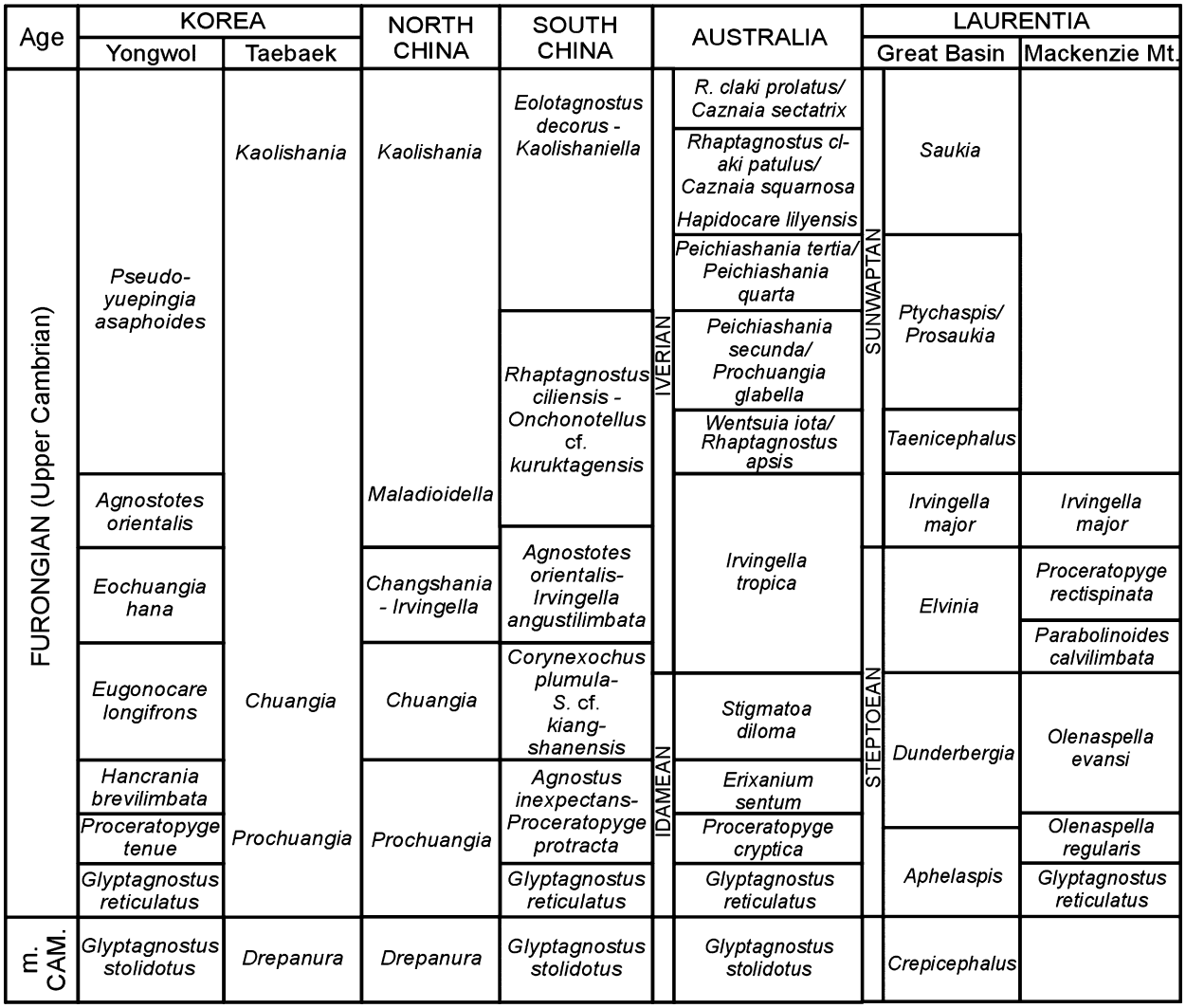

Fig. 2. Correlation of the middle Furongian (Upper Cambrian) trilobite biozones of Korea with those of other parts of the world. Modified from Geyer and Shergold (2000) and Hong et al. (2003b).

2004) and six polymerid trilobites. Polymerids include *Proceratopyge rectispinata* (Troedsson, 1937), *P. asaphoides* (Kobayashi, 1962), *Metachangshania* sp., *Jingxiania* sp. cf. *J. beigongliensis* Chien in Lu et al., 1974, *Wuhuia* sp., and olenid gen. and sp. indeterminate (Fig. 1). *Proceratopyge*, *Pseudoyuepingia* and *Wuhuia* are relatively long-ranging taxa within the Furongian. *Jingxiania*-yielding trilobite assemblages from Anhui province (Qian, 1985) were correlated with the *Ptychaspis–Tsinania* and *Quadraticephalus* Zones of North China. Accordingly it is difficult to correlate precisely this zone with North China and other parts of the world and the suggested correlation of the *P. asaphoides* Zone in Fig. 2 is provisionally based on the stratigraphic relationship of underlying biozones.

3. Systematic paleontology

The morphological terms generally follow Whittington and Kelly (1997), but the glabella used herein excludes the occipital ring. All of the specimens described in this paper are stored in the paleontological collections of Seoul National University, Korea (SNUP).

Order ASAPHIDA Salter, 1864

Superfamily ANOMOCAROIDEA Poulsen, 1927

Family PTEROCEPHALIIDAE Kobayashi, 1935

Genus ***Dikelocephalites*** Sun, 1935

Type-species: *D. flabelliformis* Sun, 1935 from the *Changshania* Zone of the Changshan Formation, Kaiping Basin, Hebei province, China (by original designation).

Remarks: the genus *Dikelocephalites* is characterized by a cranidium of low convexity with a very long frontal area and small palpebral lobes located close to the glabella, and a semi-elliptical pygidium with a short axis, and a very broad border and doublure. *Dikelocephaloides* Qian, 1994 was differentiated from *Dikelocephalites* by bottle-shaped glabella with inflated posterior portion. However, the feature quoted by Qian (1994) seems to be suitable for specific rather than generic differentiation, and thus *Dikelocephaloides* is synonymized with *Dikelocephalites*.

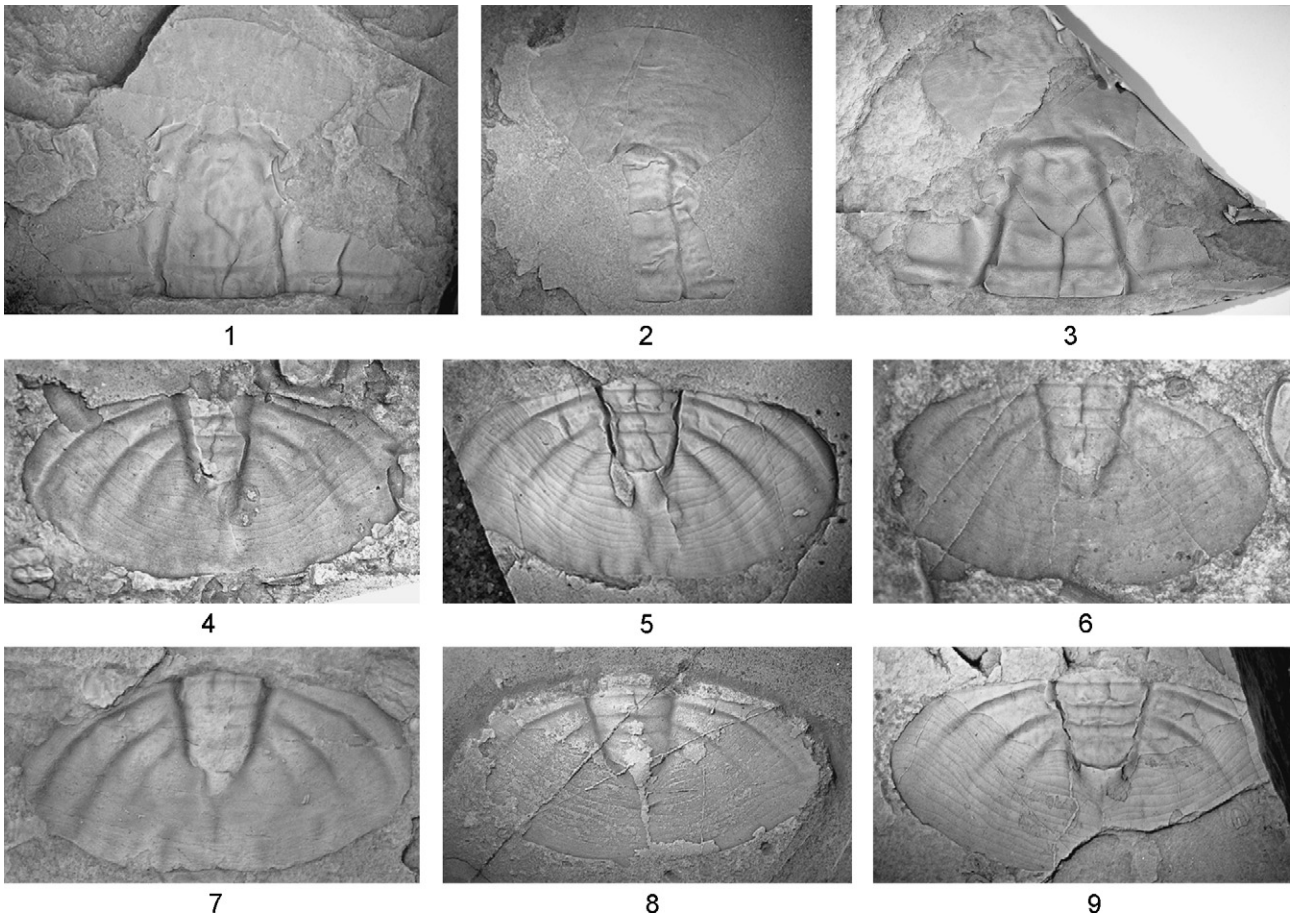

Fig. 3. **1–9**. *Dikelocephalites flabelliformis* Sun, 1935. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 795, cranidium, × 1.5; **2** SNUP 796, incomplete cranidium, × 1.2; **3** SNUP 797, latex cast of external mould of cranidium, × 1.5; **4** SNUP 798, pygidium, × 3; **5** SNUP 799, pygidium, × 1.1; **6** SNUP 800, pygidium, × 2.8; **7** SNUP 801, latex cast of external mould of pygidium, × 2.5; **8** SNUP 802, pygidium, × 2; **9** SNUP 803, incomplete pygidium, × 2.

Dikelocephalites flabelliformis Sun, 1935
Fig. 3(1–9)

1935. *D. flabelliformis* – Sun, p. 36, Pl. 2, Figs. 1–6.

1962. *Coosia* (?) sp. – Kobayashi, p. 105, Pl. 3, Fig. 24.

1962. *Briscoia* (?) sp. – Kobayashi, p. 117, Pl. 3, Fig. 23.

1980. *D. flabelliformis* Sun – Lu and Zhu, p. 10, Pl. 2, Figs. 1–4.

1983. *Dikelocephalites gigantometopus* – Lu and Qian, p. 241, Pl. 1, Fig. 10.

1994. *Dikelocephalites gigantometopus* Lu and Qian – Qian, p. 60, Pl. 6, Fig. 1.

1994. *Dikelocephalites truncata* – Qian, p. 61, Figs. 6, 8 and 9.

1995. *D. flabelliformis* Sun – Zhang et al., p. 80, Pl. 35, Figs. 2 and 3.

Material, horizon and locality: three cranidia and 11 pygidia; *E. hana* Zone of the Machari Formation; units KG-9 to KG-14 of the Konggiri section, Yongwol.

Remarks: the present material accords well with the description and illustrations of *D. flabelliformis* provided by Lu and Zhu (1980). *D. gigantometopus* Lu and Qian, 1983 is closely similar to, and cannot be distinguished from, the type species. *D. truncata* Qian, 1994 was differentiated from the type species by the presence of an anterior border, an occipital node, and numerous fine terrace lines, but all of these features may be easily modified by taphonomic processes. For instance, Zhang et al. (1995) have shown the specimens of *D. flabelliformis* with well-defined terrace lines. Consequently *D. gigantometopus* and *D. truncata* are considered junior synonyms of *D. flabelliformis*. Reexamination of the pygidia referred to *Coosia* (?) sp. and *Briscoia* (?) sp. from the *Eochuangia* Zone of the Machari Formation by Kobayashi (1962) reveals that they represent *D. flabelliformis* with original convexity.

This species differs from *Dikelocephalites gongxianensis* Meng in Zhou et al., 1977 which is characterized by sinuate, rather than straight, axial furrows and a pair of bacculae located close to the glabellar base. *Dikelocephaloides tunus* Qian, 1994 also possesses these features and hence is treated as a junior synonym of *D. gongxianensis*.

Genus ***Metachangshania*** Duan, 1966.

Type-species: *Metachangshania orientalis* Duan, 1966 from the Upper Cambrian Changshan Formation, Liaoning province, China (by original designation).

Remarks: *Metachangshania* was erected to comprise cranidia having a truncatoconical glabella with poorly-

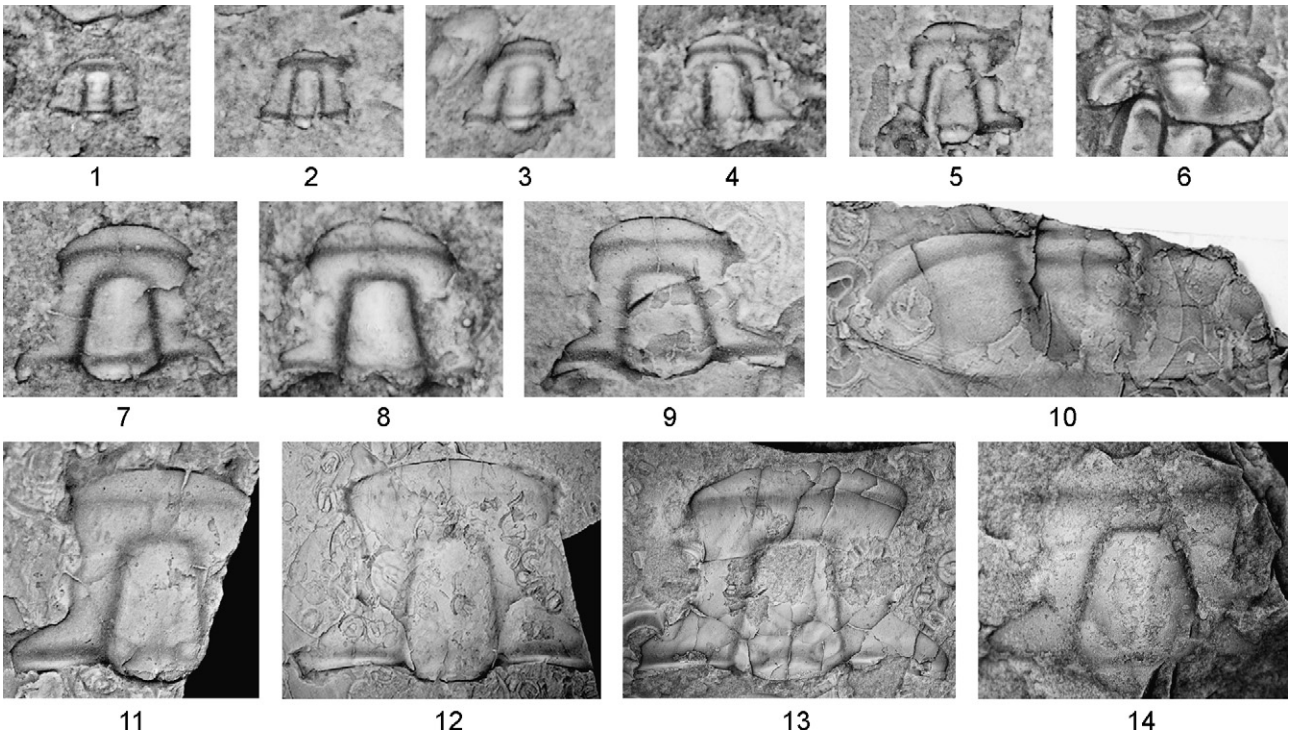

Fig. 4. **1–13**. *Metachangshania brachypyga* sp. nov. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 804, juvenile cranidium, × 8; **2** SNUP 805, juvenile cranidium, × 8; **3** SNUP 806, cranidium, × 8; **4** SNUP 807, cranidium, × 6; **5** SNUP 808, cranidium, × 7; **6** SNUP 809, pygidium, × 8; **7** SNUP 810, cranidium, × 8.5; **8** SNUP 811, cranidium, × 9; **9** Holotype, SNUP 812, cranidium, × 6; **10** SNUP 813, latex cast of external mould of incomplete pygidium, × 3; **11** SNUP 814, incomplete cranidium, × 3.8; **12** SNUP 815, cranidium, × 1.4; **13** SNUP 787, cranidium, × 1.4; **14** *Metachangshania* sp. SNUP 816, cranidium, × 2.

impressed glabellar furrows, small palpebral lobes located in front of glabellar midpoint, a preglabellar area differentiated into a convex preglabellar field and anterior border, and a transverse pygidium. Zhang et al. (1995) suggested that *Metachangshania* be placed in synonymy with *Changshania* Sun, 1924, but *Changshania* is distinct in having longer palpebral lobes placed level with or behind the glabellar midpoint, clearly-incised palpebral furrows, and a flat to concave preglabellar field. *Metachangshania* also bears some resemblance to *Pseudaphelaspis* Lu and Zhu, 1980, which is characterized by longer palpebral lobes and a longer and more upturned anterior cranidial border.

The genus *Metachangshania* was originally assigned to the family Changshaniidae (Duan, 1966; Guo and Duan, 1978), but is better accommodated with the concept of Pterocephaliidae defined by Palmer (1965) in having a truncato-conical glabella with poorly defined glabellar furrows, a frontal area differentiated into preglabellar area and anterior border, and palpebral lobes located at glabellar mid-length.

Metachangshania brachypyga nov. sp.

Fig. 4(1–13)

1962. *Lisania conica* – Kobayashi, (pars), p. 36, Pl. 5, Fig. 4 only (non Fig. 3).

Etymology: from *brachys*, short and *pyge*, rump; referring to the short pygidial axis.

Material, horizon and locality: holotype cephalon, SNUP 812 [Fig. 4(9)]; paratypes, SNUP 787, 804–811, 813–815; 17 cranidia and two pygidia; *E. hana* Zone of the Machari Formation; units KG-7 to KG-16 of the Konggiri section, Yongwol.

Diagnosis: a species of *Metachangshania* having a weakly forward tapering glabella and a short pygidium with two axial rings.

Description: cranidium subrectangular in outline. Glabella subtrapezoidal, 0.5 to 0.55 of cranidial length, longer than wide, tapering forward, with truncated glabellar front; lateral glabellar furrows faintly impressed; S1 directed obliquely rearward, convex; S2 and S3 obsolete. LO lens-shaped, narrower than glabellar base. SO composite, shallow, but distinctly incised. Frontal area divided into weakly convex preglabellar field and weakly elevated anterior border by shallow and nearly transverse anterior cranidial border furrow. Palpebral area broad, ca. one-half of glabellar width. Eye ridge narrow, weakly elevated. Facial suture opisthoparian; anterior branch of facial suture parallel-sided to slightly divergent, convex; posterior branch of facial suture strongly divergent, sinuous. Palpebral lobes crescentic, small in size, ca. one-fourth of occipital glabellar length, located at glabellar mid-length. Posterior border ridge-like, as broad as maximum glabellar width, defined by deep border furrow.

Pygidium transversely fusiform in outline, two to three times wider than long. Axis convex, tapering rearward, one-fourth to one-third of pygidial width, reaching to posterior border furrow, composed of two short axial rings and a terminal piece. Pleural field weakly convex, downsloping marginally, smooth except clearly incised anteriormost pleural furrows. Border narrow, indicated by shallow border furrow.

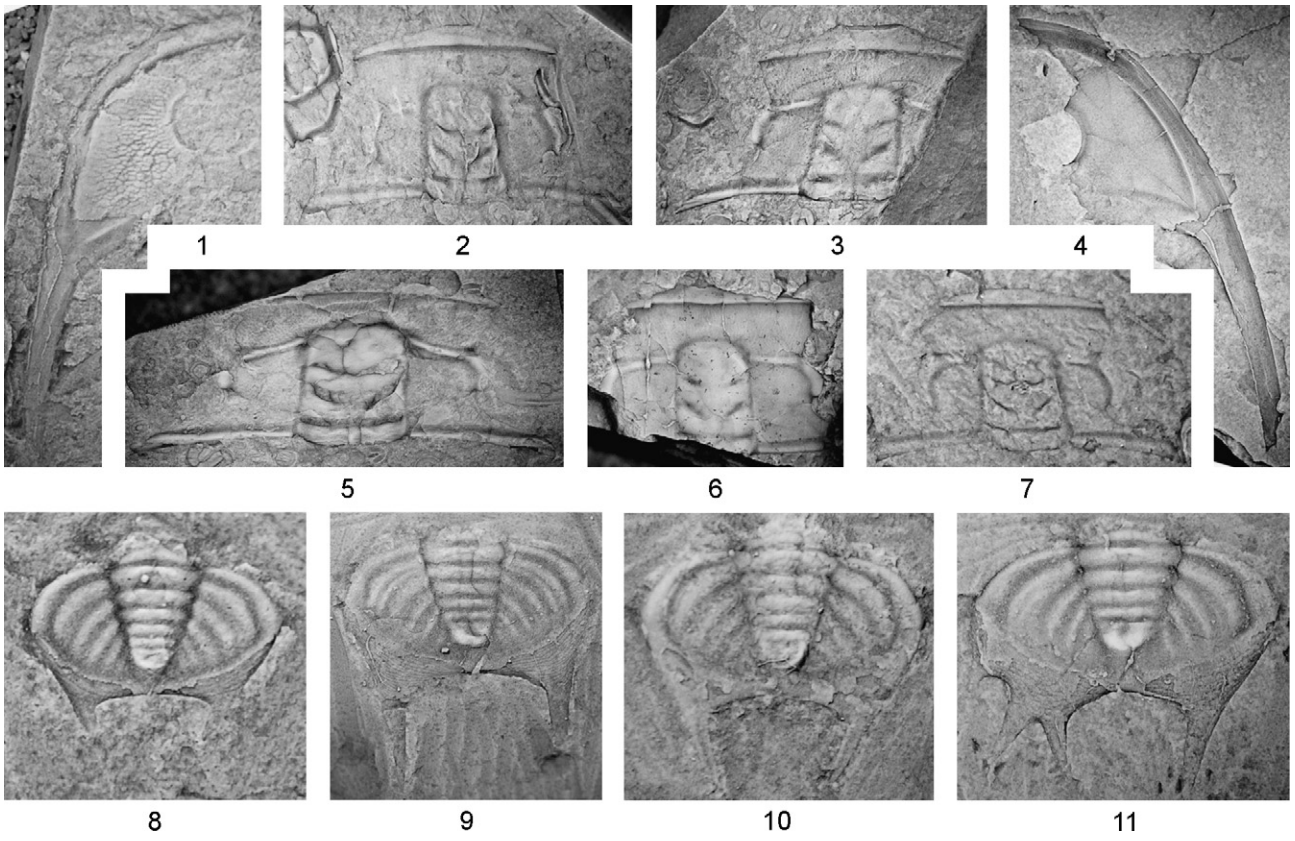

Fig. 5. **1–11**. *Pseudeugonocare bispinatum* (Kobayashi, 1962). All of the specimens are preserved as internal moulds. **1** SNUP 817, librigena, × 2; **2** SNUP 818, cranidium, × 2; **3** SNUP 819, incomplete cranidium, × 2; **4** SNUP 820, librigena, × 1.8; **5** SNUP 821, cranidium, × 1.2; **6** SNUP 822, incomplete cranidium, × 1.2; **7** SNUP 823, cranidium, × 4; **8** SNUP 1301, pygidium, × 10.5; **9** SNUP 824, pygidium, × 3.5; **10** SNUP 825, pygidium, × 6.2; **11** SNUP 1215, pygidium with malformed spines, × 4.2.

Remarks: the specimens on hand are invariably preserved flattened dorso-ventrally. This species differs from the type species, *M. orientalis*, by its narrower and less forward-tapering glabella and shorter pygidium with two, rather than four, axial rings. The pygidium assigned to *Lisania conica* by Kobayashi (1962) is identical to this species and hence is included in the synonymy.

The present collection comprises a number of specimens representing various ontogenetic stages. The smallest cranidium [Fig. 4(1)] is 1.0 mm long and 1.4 mm wide, whereas the largest one [Fig. 4(13)] measures 23 mm long and 31 mm wide. The notable morphological changes with growth are as follows: the juvenile cranidia have cylindrical glabella with clearly incised lateral glabellar furrows and very short preglabellar field, whereas the large holaspid specimens are characterized by truncato-conical glabella with faintly incised lateral glabellar furrows and longer preglabellar field.

Metachangshania sp.

Fig. 4(14)

Material, horizon and locality: one cranidium; *P. asaphoides* Zone of the Machari Formation; units KG-36 of the Konggiri section, Yongwol.

Remarks: a fragmentary cranidium from the *P. asaphoides* Zone is too poorly preserved to be identified to the species level, but may be comparable to *M. orientalis* Duan, 1966 from the Changshan Formation of Liaoning province.

Genus ***Pseudeugonocare*** Peng, 1992

Type species: *Eugonocare* (*Pseudeugonocare*) *camptodromum* Peng, 1992 from the *A. orientalis–I. angustilimbata* Zone, South China (by original designation).

Remarks: Peng (1992) distinguished three subgenera of *Eugonocare* Whitehouse, 1936 based on pygidial morphology: *Eugonocare* (*E.*) lacks marginal spines; *E.* (*Olenaspella*) Wilson, 1956 has one to three pairs of slender marginal spines; and *E.* (*Pseudeugonocare*) Peng, 1992 is characterized by a pair of broadly based spines. However, the diagnostic feature of *E.* (*Pseudeugonocare*) is quite distinctive and *E.* (*Pseudeugonocare*) is elevated herein to the generic level. In addition to the type species, Peng (1992) allocated five species to the genus: they are *Crepicephalus borealis* Lermontova, 1940; *Koptura bispinata* Kobayashi, 1962; *Olenaspella consimila* Ergaliev, 1980; *Olenaspella hunanensis* Zhou in Zhou et al., 1977; and with reservation *Olenaspella fenghuangensis* Zhou in Zhou et al., 1977.

Pseudeugonocare bispinatum (Kobayashi, 1962)

Fig. 5(1–11)

1962. *Koptura bispinata* – Kobayashi, (pars), p. 101, Pl. 7, Figs. 1–4, 6 and 7 (non Fig. 5).

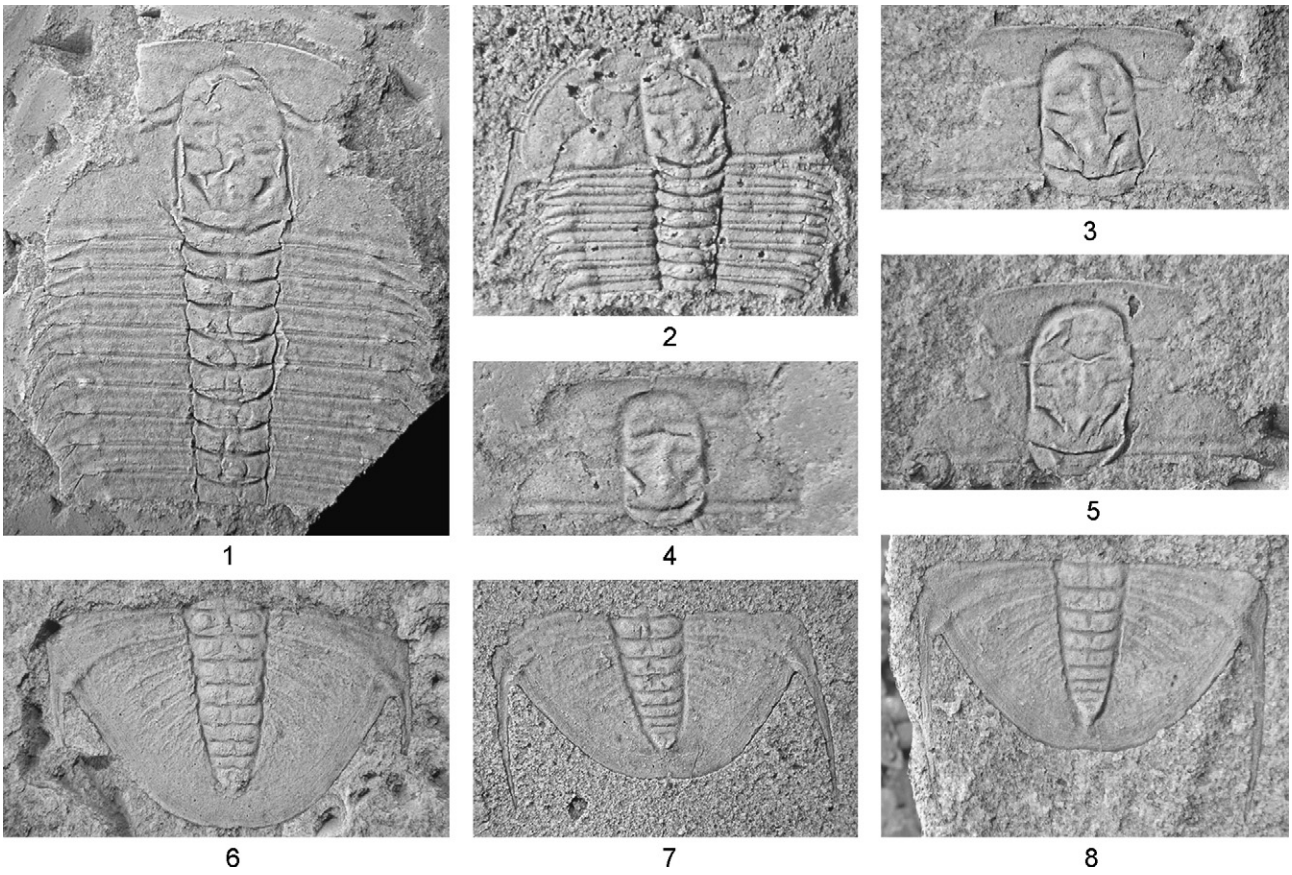

Fig. 6. **1–8**. *Proceratopyge promisca* sp. nov. All of the specimens are preserved as internal moulds. **1** SNUP 826, incomplete carapace, × 6; **2** SNUP 827, incomplete carapace, × 8; **3** SNUP 828, cranidium, × 6; **4** SNUP 829, cranidium, × 8; **5** Holotype, SNUP 830, cranidium, × 7.5; **6** SNUP 831, pygidium, × 4; **7** SNUP 832, pygidium, × 4.2; **8** SNUP 833, pygidium, × 6.5.

1962. *Koptura* cf. *bispinata* – Kobayashi, p. 103, Pl. 10, Fig. 12.

1992. *Eugonocare* (*P.*) *bispinatum* (Kobayashi) – Peng, p. 60.

2001. *Eugonocare* (*P.*) *bispinatum* (Kobayashi) – Lee et al., p. 216, Fig. 1.

Material, horizon and locality: 15 cranidia, eight pygidia, and seven free cheeks; *E. hana* and *A. orientalis* Zones of the Machari Formation; units KG-3 to KG-32 of the Konggiri section, Yongwol.

Remarks: this species is characterized by a broad and short pygidial axis with four to five axial rings and a terminal piece and a pair of pygidial spines situated close to each other. Among the type material, the librigena (Kobayashi, 1962: Pl. 7, Fig. 5) referred to this species belongs to *E. hana*. *Pseudeugonocare consimila* from Kazakhstan is similar to this species, but differs in having a longer pygidial axis which extends to the border furrow. The two species from South China, *P. camptodromum* and *P. hunanense*, have a more slender pygidial axis with more axial rings and widely separated marginal spines.

Lee et al. (2001) reported the occurrence of a teratological pygidium of *P. bispinatum* from the Konggiri section [refigured in Fig. 5(11)]. The pygidium has a normal spine on the right, but bears three malformed spines on the left. They interpreted that the asymmetric abnormality was caused by genetic defect, but may suggest an evolutionary novelty in the *Eugonocare* lineage.

Superfamily ASAPHOIDEA Burmeister, 1843

Family CERATOPYGIDAE Linnarsson, 1869

Subfamily PROCERATOPYGINAE Wallerius, 1895

Genus ***Proceratopyge*** Wallerius, 1895

Type-species: *Proceratopyge conifrons* Wallerius, 1895 from the *Lejopyge laevigata* Zone of Sweden (by original designation).

Remarks: *Proceratopyge* is a cosmopolitan genus documented from upper Middle Cambrian to Furongian strata of various parts of the world. Generic concept and taxonomic complexity of *Proceratopyge* has been extensively discussed in the literature (Kobayashi, 1962; Öpik, 1963; Palmer, 1968; Henderson, 1976; Shergold, 1982; Rushton, 1983; Jago, 1987; Webby et al., 1988; Lu and Lin, 1989; Peng, 1992; Pratt, 1992; Lee and Choi, 1995; Yuan and Yin, 1999). Some authors employed subgeneric divisions for *Proceratopyge* based on cranidial morphological features and the number of pygidial axial rings (Kobayashi, 1962; Öpik, 1963; Shergold, 1982; Lu and Lin, 1989; Peng, 1992; Yuan and Yin, 1999), whereas others favored a single genus because the criteria for discriminating subgenera are equivocal (Henderson, 1976;

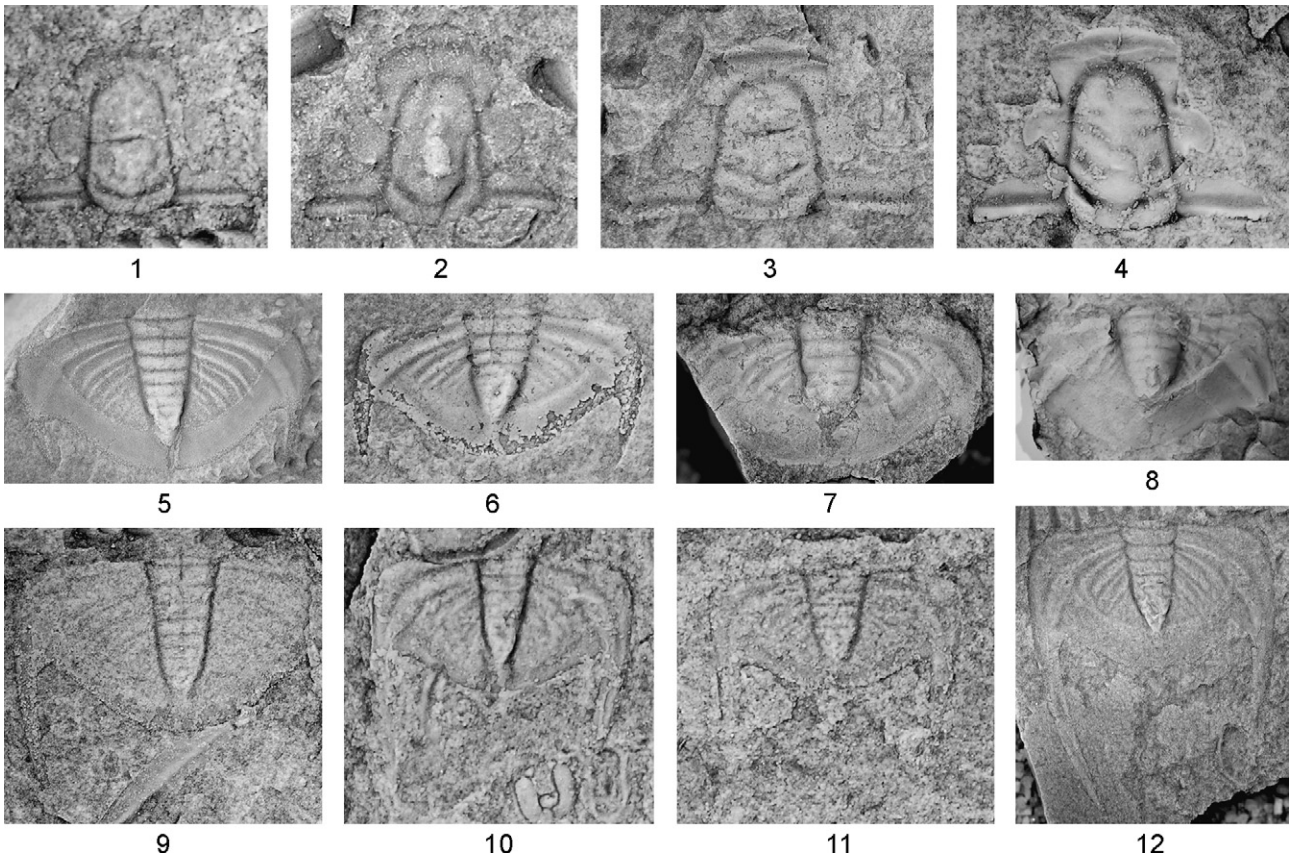

Fig. 7. **1–12**. *Proceratopyge rectispinata* (Troedsson, 1937). All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 834, cranidium, × 5.5; **2** SNUP 835, cranidium, × 5.2; **3** SNUP 836, cranidium, × 4; **4** SNUP 837, cranidium, × 4; **5** SNUP 838, pygidium, × 2; **6** SNUP 839, pygidium, × 4; **7** SNUP 840, incomplete pygidium, × 1.8; **8** SNUP 841, latex cast of external mould of incomplete pygidium, × 1.5; **9** SNUP 842, pygidium, × 4.2; **10** SNUP 843, pygidium, × 5.5; **11** SNUP 844, pygidium, × 5.5; **12** SNUP 845, pygidium, × 2.

Rushton, 1983; Jago, 1987; Webby et al., 1988; Pratt, 1992; Lee and Choi, 1995). The latter view is followed in this study.

Proceratopyge is a very large group comprising more than 70 species (Rushton, 1983; Lee and Choi, 1995; Yuan and Yin, 1999). Apparently too many species have been assigned to *Proceratopyge* and comprehensive taxonomic revision will reduce significantly the number of species within the genus.

Proceratopyge promisca sp. nov.

Fig. 6(1–8)

Etymology: from *promiscuus*, mixed: referring to mixed morphological features of this species within *Proceratopyge*.

Material, horizon and locality: holotype cranidium SNUP 830 [Fig. 6(5)]; paratypes SNUP 826–829, 831–833; more than 100 specimens including three incomplete carapace; *E. hana* and *A. orientalis* Zones of the Machari Formation; units KG-2 to KG-26 of the Konggiri section, Yongwol.

Diagnosis: a species of *Proceratopyge* having strongly divergent anterior branches of facial sutures, thread-like anterior cranidial border, small palpebral lobes situated in front of glabellar midpoint, and a long pygidium with eight axial rings.

Description: cranidium subtrapezoidal in outline, wider than long, with nearly transverse to weakly convex frontal margin. Glabella parallel-sided with broadly rounded anterior margin and a small median node on L2, 1.5 times longer than wide; four pairs of glabellar furrows, not connected to axial furrows; S1 bifurcate, directed obliquely rearwards; S2 and S3 more or less transverse, S2 longer than S3; S4 short, directed obliquely forwards; axial furrows shallow, clearly-incised. SO composite, arched rearwards; LO of uniform length, short. Frontal area 0.1 to 0.15 of cranidial length, flat, with paradoublural lines, mostly represented by preglabellar area; anterior border thread-like. Anterior branch of facial suture strongly divergent forwards at ca. 30° to sagittal line, then converging along anterior margin of cranidium to meet at ogival point. Palpebral lobes crescentic, small, situated in front of glabellar mid-length, ca. one-half of glabellar width away from axial furrows; eye-ridges elevated. Posterior area of fixigenae long and broad, broader than long, broader than glabella; posterior border transverse, as long as one-half of occipital ring, well defined by shallow posterior border. Posterior branch of facial suture divergent convex.

Pygidium semi-circular to subtriangular in outline, 1.6 to 1.8 times wider than long, flat. Axis clearly defined by axial furrows, 0.85 to 0.88 of pygidial length, weakly tapering rearward, with eight axial rings and a terminal piece. Anterior five to six pairs of pleural and interpleural furrows impressed;

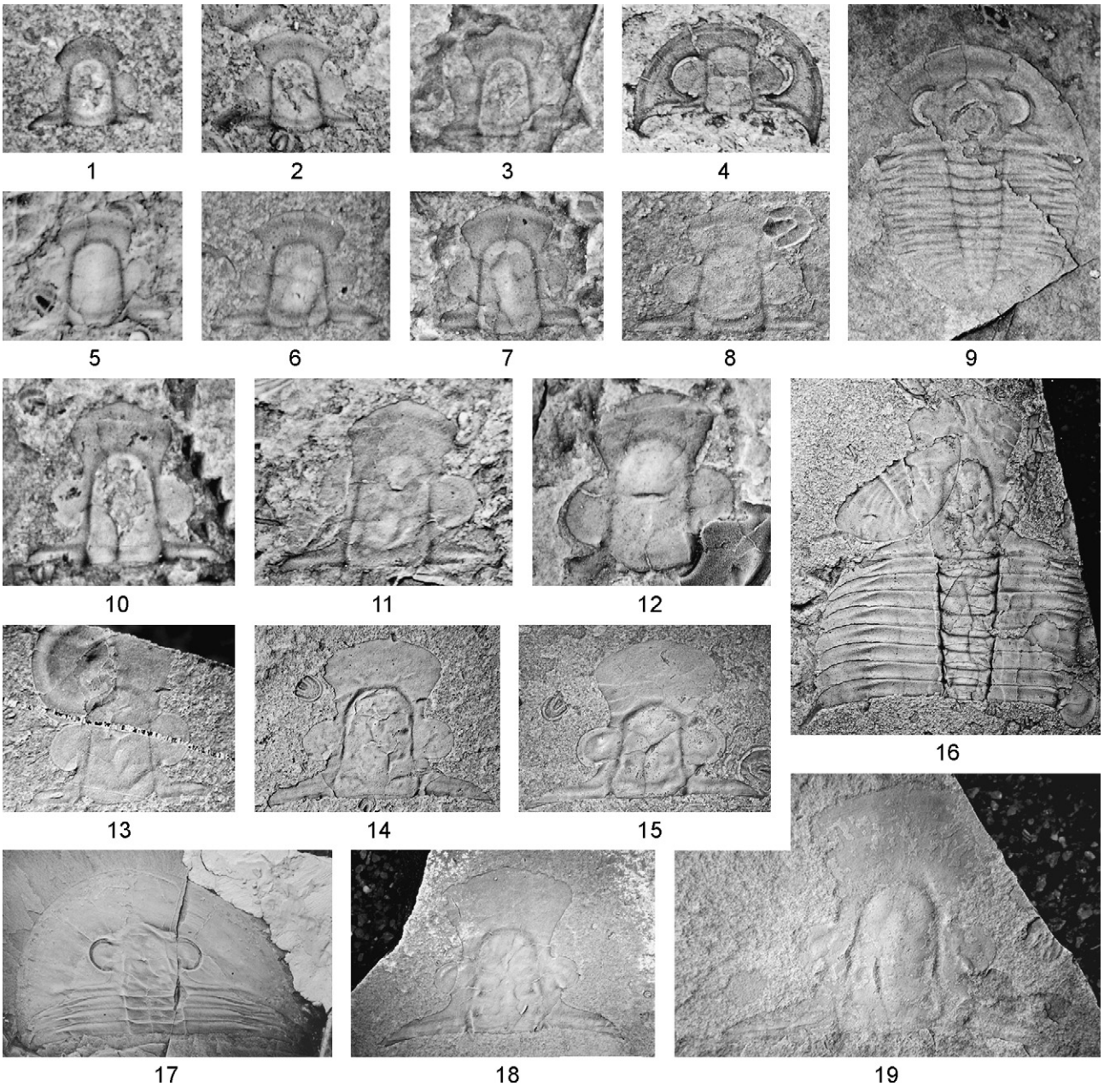

Fig. 8. **1–19**. *Haniwoides longus* Kobayashi, 1935. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 846, small cranidium, × 6.5; **2** SNUP 847, cranidium, × 6; **3** SNUP 848, cranidium, × 6; **4** SNUP 849, cephalon, × 4; **5** SNUP 850, cranidium, × 6; **6** SNUP 851, cranidium, × 6; **7** SNUP 852, cranidium, × 6; **8** SNUP 853, cranidium, × 5; **9** SNUP 854, latex cast of external mould of carapace, × 5; **10** SNUP 855, cranidium, × 6; **11** SNUP 856, cranidium, × 6; **12** SNUP 857, cranidium, × 4.5; **13** SNUP 858, cranidium, × 3; **14** SNUP 859, cranidium, × 3; **15** SNUP 860, cranidium, × 2; **16** SNUP 861, incomplete carapace, × 1.8; **17** SNUP 862, latex cast of external mould of cephalon with three thoracic segments, × 1; **18** SNUP 863, cranidium, × 2; **19** SNUP 864, cranidium, × 1.5.

each pleura consisting of shorter anterior band and longer posterior band. Anteriormost pleural segment prolonged into a pair of slender spines; spines slightly longer than pygidial length, directed rearward; pleural and interpleural furrows of posterior pleurae not extending beyond paradoublural line. Border of uniform width, as broad as 0.15 of pygidial length, defined by faint border furrow. Doublure twice as wide as border.

Remarks: *P. promisca* nov. sp. displays the combined morphological features of three subgenera favored by Lu and Lin (1980) and Yuan and Yin (1999): that is, subcylindrical glabella, short frontal area, strongly divergent anterior branches of facial sutures, anteriorly located small palpebral lobes, broad posterior area, and long pygidium with eight axial rings. Jago (1987) rejected the subgeneric subdivision of the genus, but recognized two morphological groups of *Proceratopyge* based on cranidial features: one is characterized by small and anteriorly-located palpebral lobes, large posterior area, and less divergent anterior branches of facial suture, while the other has larger, semicircular, and more centro-posteriorly located palpebral lobes, strap-like posterior area, and strongly divergent

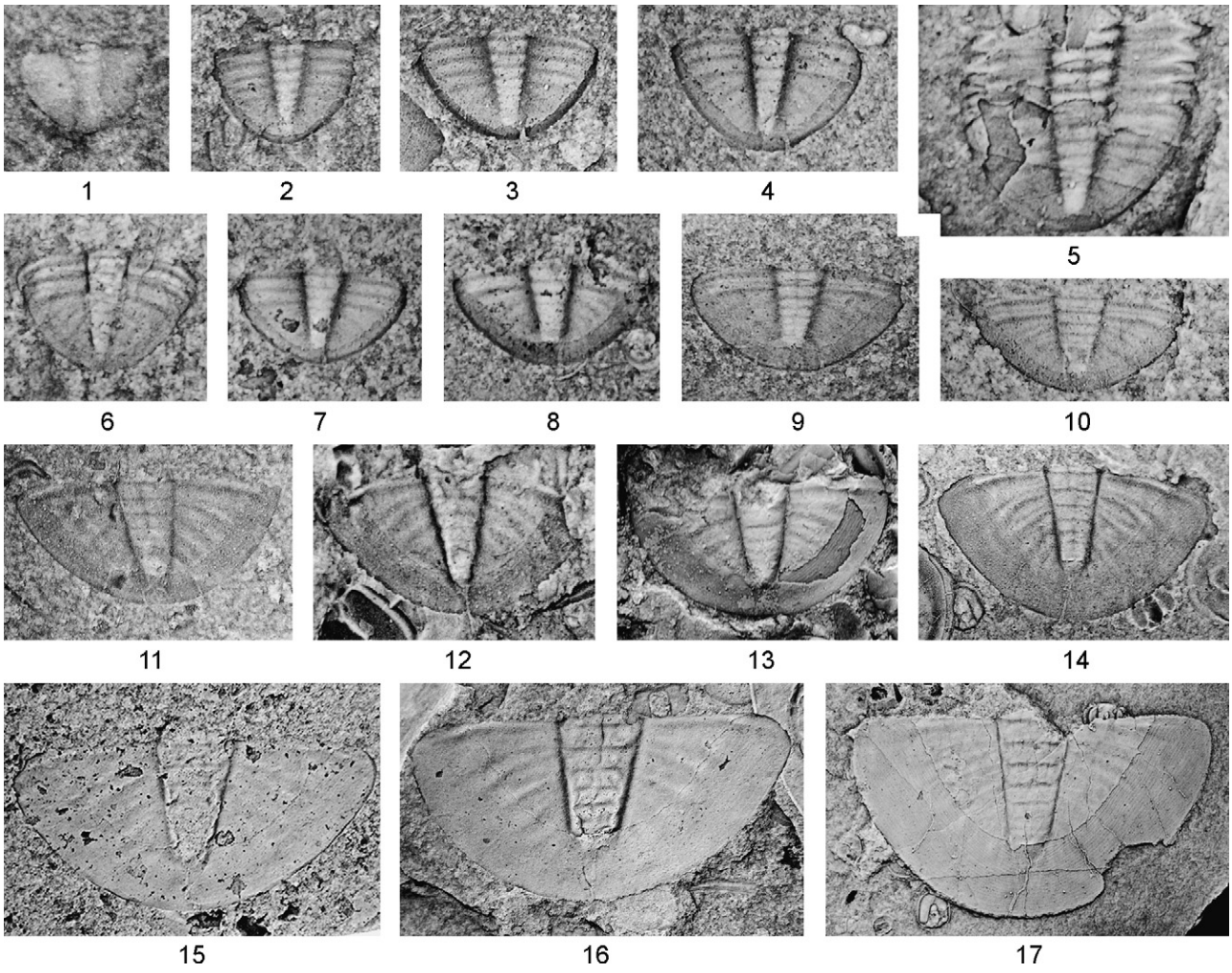

Fig. 9. **1–17**. *Haniwoides longus* Kobayashi, 1935. All of the specimens are preserved as internal moulds. **1** SNUP 865, juvenile pygidium, × 8.5; **2** SNUP 866, pygidium, × 5; **3** SNUP 867, pygidium, × 7; **4** SNUP 868, pygidium, × 6; **5** SNUP 869, incomplete thoracopygon, × 7.5; **6** SNUP 870, pygidium, × 8.5; **7** SNUP 871, pygidium, × 6; **8** SNUP 872, pygidium, × 6; **9** SNUP 873, pygidium, × 6; **10** SNUP 874, pygidium, × 5; **11** SNUP 875, pygidium, × 6; **12** SNUP 876, pygidium, × 7; **13** SNUP 877, pygidium, × 3.5; **14** SNUP 878, pygidium, × 3.5; **15** SNUP 879, pygidium, × 5; **16** SNUP 880, pygidium, × 4; **17** SNUP 881, pygidium, × 2.5.

anterior branches of facial suture. However, *P. promisca* nov. sp. cannot be assigned to either morphological group, which may explain why subgeneric divisions of *Proceratopyge* have not been employed in this study.

Proceratopyge rectispinata (Troedsson, 1937)

Fig. 7(1–12)

1937. *Lopnorites rectispinatus* – Troedsson, p. 35, Pl. 2, Figs. 1, 2.

1937. *Lopnorites fragilis* – Troedsson, p. 36, Pl. 2, Figs. 3–6.

1955. *Lopnorites rectispicatus* – Kobayashi and Ichikawa, p. 67, Pl. 11, Fig. 16.

1961. *Proceratopyge cylindrica* – Chien, p. 107, Pl. 3, Figs. 8–10.

1985. *Proceratopyge copiosa* – Xiang and Zhang, p. 131, Pl. 46, Figs. 1–4.

1985. *Proceratopyge mitis* – Xiang and Zhang, p. 132, Pl. 45, Figs. 7–9.

1985. *Proceratopyge proparia* – Xiang and Zhang, p. 132, Pl. 46, Figs. 6–10.

1985. *Proceratopyge yardanshanensis* – Xiang and Zhang, p. 133, Pl. 47, Figs. 2–10.

1989. *Proceratopyge* (*Proceratopyge*) *distensa* – Lu and Lin, p. 149, Pl. 24, Figs. 9–11.

1992. *P. rectispinata* (Troedsson) – Pratt, p. 45, Pl. 8, Figs. 1–12; Pl. 9, Figs. 1–15 (for additional synonymy).

1996. *Proceratopyge gamaesilensis* – Lee and Choi, p. 152, Pl. 2, Figs. 1–7.

Material, horizon, and locality: more than 100 specimens; *P. asaphoides* Zone of the Machari Formation; units KG-36 to KG-113 of the Konggiri section, Yongwol.

Remarks: *P. rectispinata* is widely documented in China, North America, and England. A comprehensive account on the species has been given by Pratt (1992) who synonymized several species while allowing a range of intraspecific variability. The present material agrees with the interpretation of the species by Pratt (1992) and also displays a range of morphological variability in the relative length of the frontal area, distinctiveness of glabellar furrows, length of pygidial spines, and breadth of pygidial border.

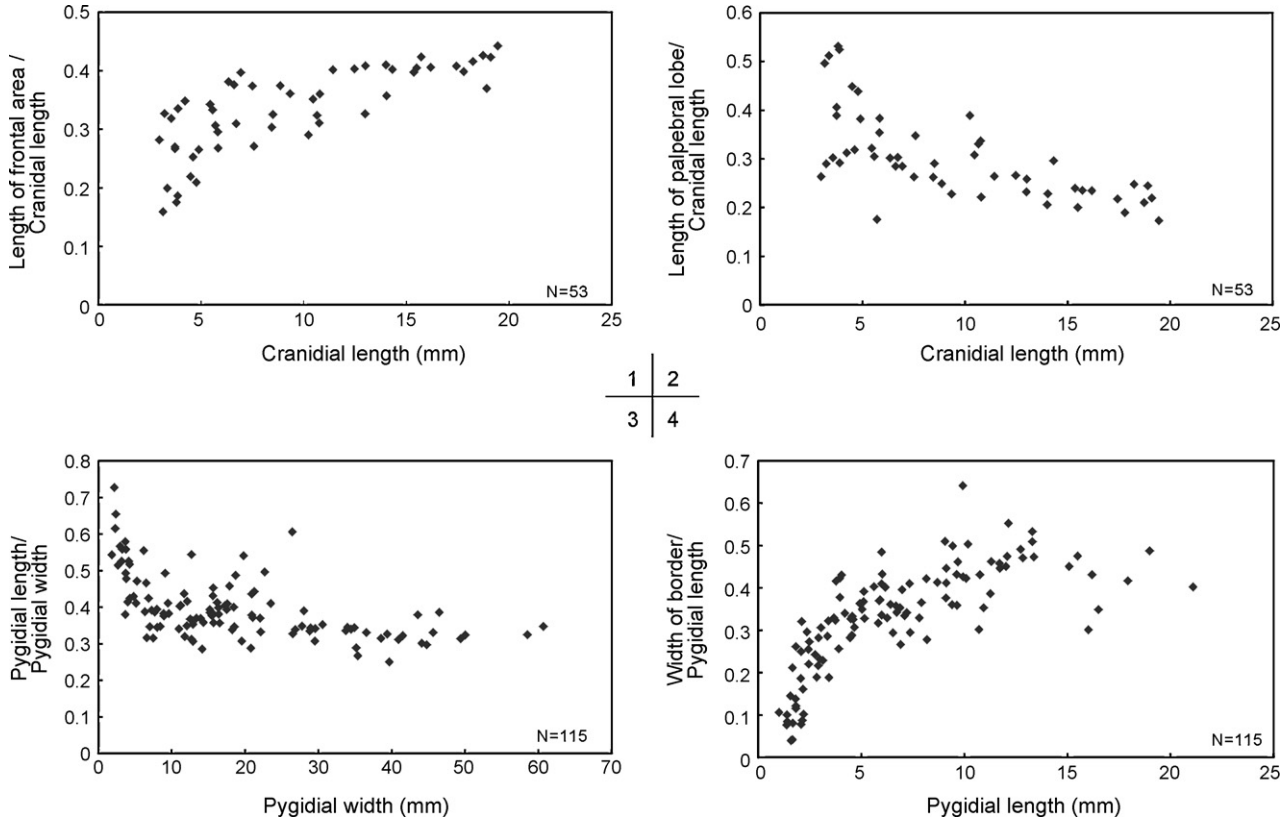

Fig. 10. **1**. Bivariate plots of the ratio of frontal area length versus cranidial length against cranidial length of the *Haniwoides longus* Kobayashi, 1935. This shows the frontal area becoming gradually longer with growth; **2** Bivariate plots of the ratio of palpebral lobe versus cranidial length against cranidial length of the *Haniwoides longus* Kobayashi, 1935. Relative length of the palpebral lobe steadily decreases with growth; **3** Bivariate plots of pygidial length against pygidial width of *Haniwoides longus* Kobayashi, 1935, showing that pygidia become more transverse with growth; **4** Bivariate plots of the ratio of width of border versus pygidial length against pygidial length of *Haniwoides longus* Kobayashi, 1935. It shows that width of border gradually increases with growth.

Subfamily IWAYASPIDINAE Kobayashi, 1962

Genus ***Haniwoides*** Kobayashi, 1935

Type-species: *H. longus* Kobayashi, 1935 from the Machari Formation, Yongwol, Korea (by original designation).

Emended diagnosis: ceratopygid trilobites having subrectangular glabella with effaced glabellar furrows; frontal area undifferentiated and relatively long; palpebral lobes moderate in size and located close to axial furrow; pygidium semi-

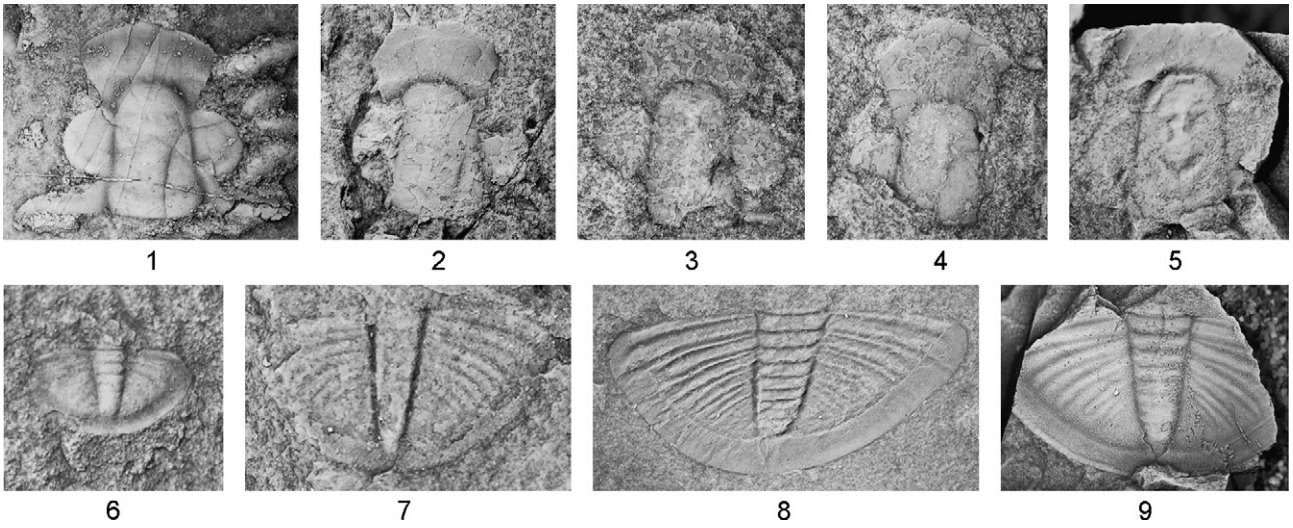

Fig. 11. **1–9**. *Pseudoyuepingia asaphoides* (Kobayashi, 1962). All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 882, latex cast of external mould of cranidium, × 3.2; **2** SNUP 883, incomplete cranidium, × 3.5; **3** SNUP 884, incomplete cranidium, × 3.5; **4** SNUP 885, incomplete cranidium, × 3; **5** SNUP 886, incomplete cranidium, × 3; **6** SNUP 887, small pygidium, × 6.5; **7** SNUP 888, pygidium, × 5.5; **8** SNUP 889, pygidium, × 3; **9** SNUP 890, incomplete large pygidium, × 1.4.

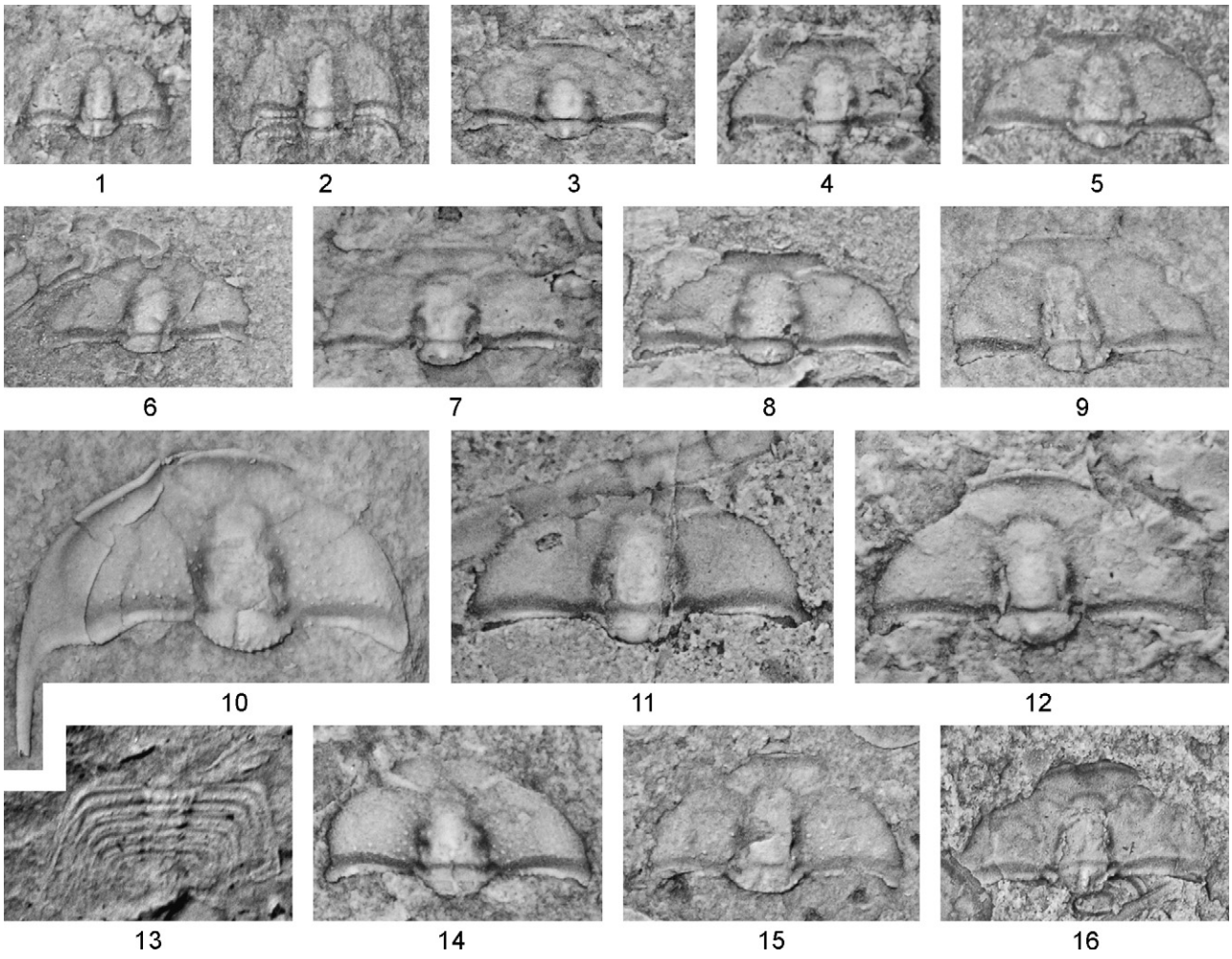

Fig. 12. **1–16**. *Joshuaspis parvus* sp. nov. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 891, juvenile cranidium, × 8.5; **2** SNUP 892, cephalon with a thoracic segment, × 9; **3** SNUP 893, cranidium, × 9; **4** SNUP 894, cranidium, × 10; **5** SNUP 895, cranidium, × 8.5; **6** SNUP 896, cranidium, × 6.5; **7** SNUP 897, cranidium, × 10.5; **8** SNUP 898, cranidium, × 7.5; **9** SNUP 899, cranidium, × 6.5; **10** holotype, SNUP 900, latex cast of external mould of incomplete cephalon, × 9.5; **11** SNUP 901, cranidium, × 9.5; **12** SNUP 902, cranidium, × 10; **13** SNUP 903, latex cast of external mould of incomplete thoracopygon, × 13; **14** SNUP 904, cranidium, × 10; **15** SNUP 905, cranidium, × 7.5; **16** SNUP 791, cranidium, × 8.

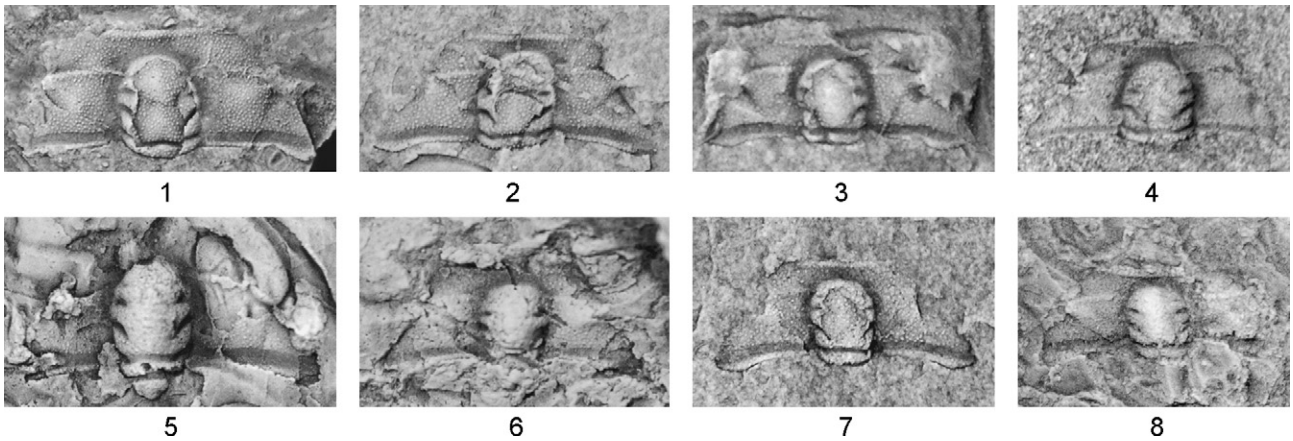

Fig. 13. **1–8**. *Macharia pengi* sp. nov. **1**. All of the specimens are preserved as internal moulds. Holotype, SNUP 906, cranidium, × 5; **2** SNUP 907, cranidium, × 6; **3** SNUP 908, cranidium, × 7; **4** SNUP 909, cranidium, × 6; **5** SNUP 910, incomplete cranidium, × 6.5; **6** SNUP 911, cranidium, × 7.5; **7** SNUP 912, cranidium, × 8.2; **8** SNUP 913, cranidium, × 6.8.

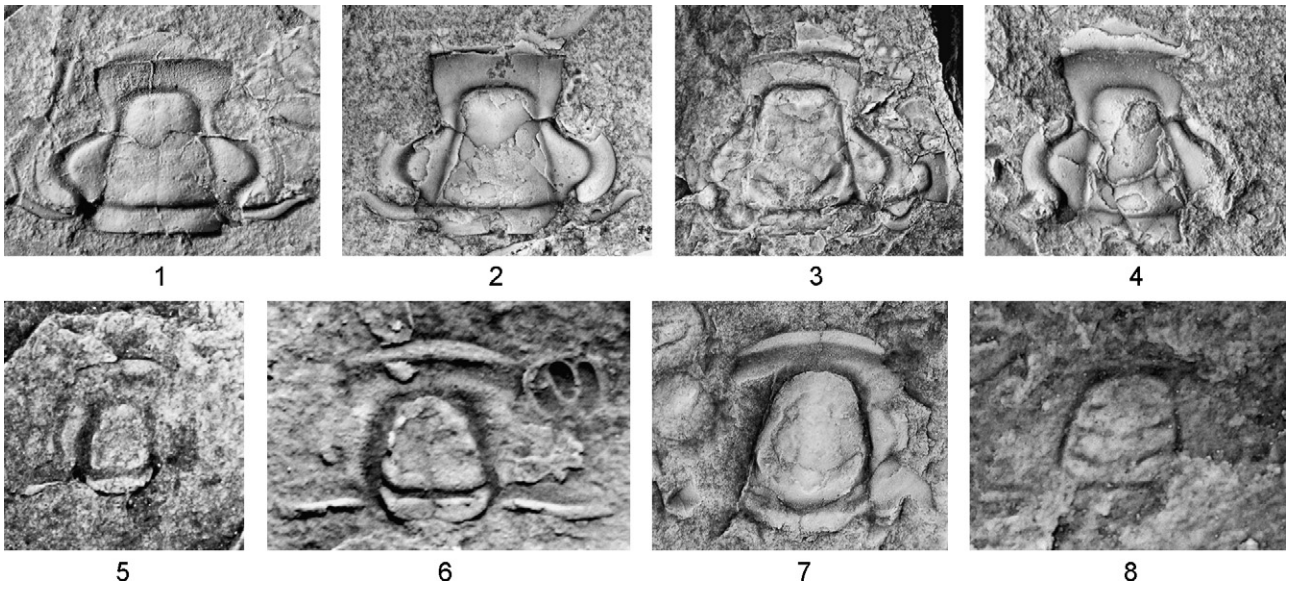

Fig. 14. **1–4**. *Changshania equalis* Sun, 1935. All of the specimens are preserved as internal moulds. **1** SNUP 783, cranidium, × 3; **2** SNUP 784, cranidium, × 3.5; **3** SNUP 785, cranidium, × 3; **4** SNUP 786, cranidium, × 3.5; **5, 6**. *Jingxiania* sp. *J. beigongliensis* Chien in Lu et al., 1974; **5** SNUP 914, internal mould of cranidium, × 9; **6** SNUP 915, latex cast of external mould of cranidium, × 8; **7** *Wuhuia* sp. SNUP 916, internal mould of cranidium, × 3.5; **8** Olenid gen. and sp. indeterminate. SNUP 917, latex cast of external mould of cranidium, × 8.2.

elliptical with entire or indented posterior margin, clearly impressed pleural and interpleural furrows, and broad doublure.

Remarks: the genus *Haniwoides* was diagnosed as having a cylindrical glabella with obscure glabellar furrows, a long concave frontal area, and semi-circular, large palpebral lobes located close to the glabella. *Haniwoides* has long been known to occur exclusively in Korea, but recently it was reported from Queensland, Australia (*Haniwoides varia* Shergold, 1980) and Hunan (*Haniwoides* sp. Peng, 1992) and Xinjiang (*Haniwoides* cf. *varia*, Xiang and Zhang, 1985), China. The cranidium assigned to *Haniwoides* sp. from Hunan, China (Peng, 1992) is too fragmentary to be evaluated, but seems better assignable to other ceratopygids.

Haniwoides was originally included within the family Anomocaridae by Kobayashi (1935, 1962), but subsequently was referred to the Ceratopygidae (Shergold, 1980; Hughes and Rushton, 1990; Peng, 1992). However, its subfamilial position has been controversial: it was assigned to the Proceratopyginae by Shergold (1980), Iwayaspidinae by Hughes and Rushton (1990), or Macropyginae by Peng (1992). We concur with Hughes and Rushton (1990) in that the iwayaspidines are a paraphyletic group of the family Ceratopygidae with non-spinose pygidia.

Closely allied genera to *Haniwoides* are *Yuepingia* Lu, 1956, *Pseudoyuepingia* Chien, 1961, *Aplotaspis* Henderson, 1976, *Tamdaspis* Lisogor, 1977, *Cermatops* Shergold, 1980, *Guozia* Xiang and Zhang, 1985, and *Sayramaspis* Xiang and Zhang, 1985. Hughes and Rushton (1990) suggested that *Yuepingia* may be junior synonyms of *Haniwoides*, but *Yuepingia* can be distinguished from *Haniwoides* by its very large, forward-tapering glabella, large palpebral lobes, and narrow frontal area.

Pseudoyuepingia is a stratigraphically younger iwayaspidine and is characterized by large palpebral lobes situated away from the glabella, a short frontal area differentiated into a preglabellar field and an anterior border, and a pygidium with eight axial rings and a narrow border. These morphological features are closely comparable to juvenile forms of *Haniwoides longus* (see below), suggesting that *Pseudoyuepingia* is likely to be a paedomorphic descendant of *Haniwoides*. *Aplotaspis* has closely comparable cranidia and pygidia to *Haniwoides*, but can be differentiated from the latter by smaller palpebral lobes and the presence of distinctive paradoublural lines. *Tamdaspis* is characterized by the presence of bacculae, whereas *Cermatops*, *Guozia*, and *Sayramaspis* have comparatively small palpebral lobes.

Haniwoides longus Kobayashi, 1935

Figs. 8(1–19) and 9(1–17)

1935. *Haniwoides longus* – Kobayashi, p. 243, Pl. 17, Figs. 2 and 3.

1935. *Haniwoides concavus* – Kobayashi, p. 243, Pl. 17, Figs.1, 16 and 17.

1962. *Haniwoides longissimus* – Kobayashi, p. 116, Pl. 2, Fig. 7.

1962. *Proceratopyge* (*Kogenium*) *rotundum* Kobayashi – Kobayashi, (pars) p. 120, Pl. 4, Figs. 6, 7, 9–11.

Material, horizon, and locality: more than 300 specimens including one complete carapace; *E. hana* and *A. orientalis* Zones of the Machari Formation; units KG-1 to KG-31 of the Konggiri section, Yongwol.

Description: cranidium subtrapezoidal, wider than long. Glabella widest at glabellar base, tapering abruptly forwards to form a parallel-sided to weakly constricted outline; moderately convex, down-sloping in anterior one-third of glabella, with rounded frontal margin and a small preoccipital node; lateral glabellar furrows effaced or pit-like. SO faint, simple, transverse; occipital ring short. Frontal area 0.25 to 0.45 of

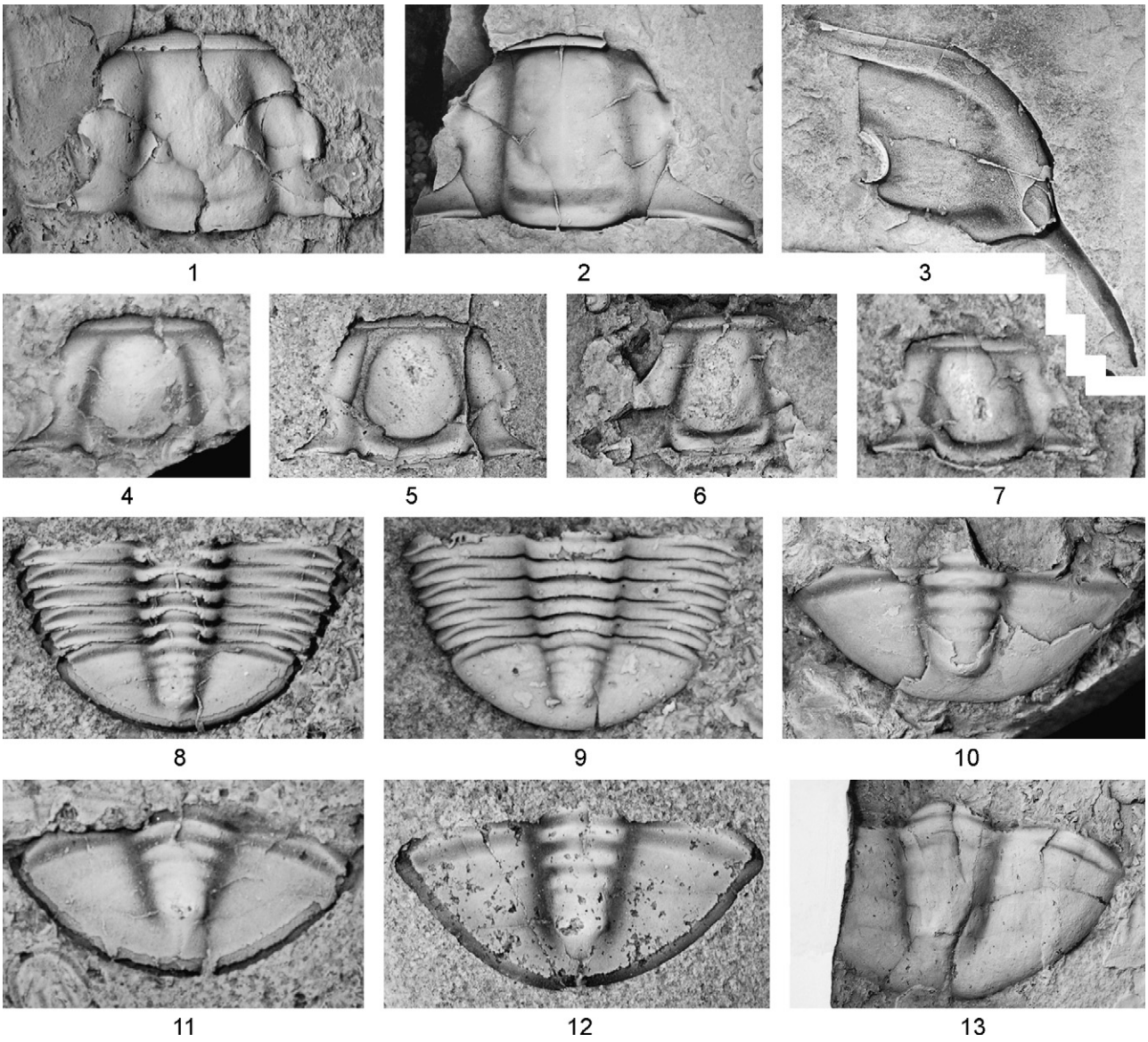

Fig. 15. **1–13**. *Chuangia* spp. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** SNUP 789, latex cast of external mould of cranidium, × 4; **2** SNUP 918, cranidium, × 2.5; **3** SNUP 919, librigena, × 3; **4** SNUP 920, cranidium, × 4; **5** SNUP 921, cranidium, × 4; **6** SNUP 922, cranidium, × 3; **7** SNUP 923, cranidium, × 5; **8** SNUP 924, incomplete thoracopygon, × 5.5; **9** SNUP 925, latex cast of counterpart of SNUP 924, × 5.5; **10** SNUP 926, pygidium, × 4; **11** SNUP 927, pygidium, × 6; **12** SNUP 928, pygidium, × 4; **13** SNUP 790, latex cast of external mould of incomplete pygidium, × 7.

cranidial length, concave, not differentiated into preglabellar field and anterior border. Anterior branch of facial suture divergent forwards with less than 30° to sagittal line, then converging along anterior margin of cranidium to meet at ogival point. Palpebral lobes semi-circular, 0.2 to 0.4 of cranidial length, situated slightly in front of glabellar mid-length, close to, but not attached to, axial furrows. Posterior area very short, as wide as occipital ring; posterior border clearly defined by border furrow. Posterior branch of facial suture markedly divergent, sinuous. Librigena with broad and gently convex genal field and short genal spines; border narrow, indicated by change in slope; eye socle ridge-like and elevated, clearly defined by shallow eye socle furrow; median suture present ventrally; doublure very broad, extending to ocular incisure, with closely spaced terrace ridges.

Pygidium semi-elliptical, three times wider than long, gently convex. Axis clearly defined by deep axial furrows, 0.7 to 0.8 of pygidial length, tapering rearward, with normally five axial rings and terminal piece. Postaxial ridge faintly indicated. Pleural furrows more clearly impressed but shorter than interpleural furrows; pleural and interpleural furrows extending to a little beyond paradoublural line, not reaching to margin. Five to six pleurae present. Pleural field and border undifferentiated. Doublure very broad, 0.3 to 0.5 of pygidial length, extending inwards to posterior end of axis.

Remarks: Kobayashi (1935) erected two species of *Haniwoides*, *H. longus* and *H. concavus*, and later in 1962 added three new species (*H. longissimus*, *H. tenuis*, and *H.*? *puteolatus*) to the genus. Of these, *H. concavus* and *H. longissimus* share many morphological features with the

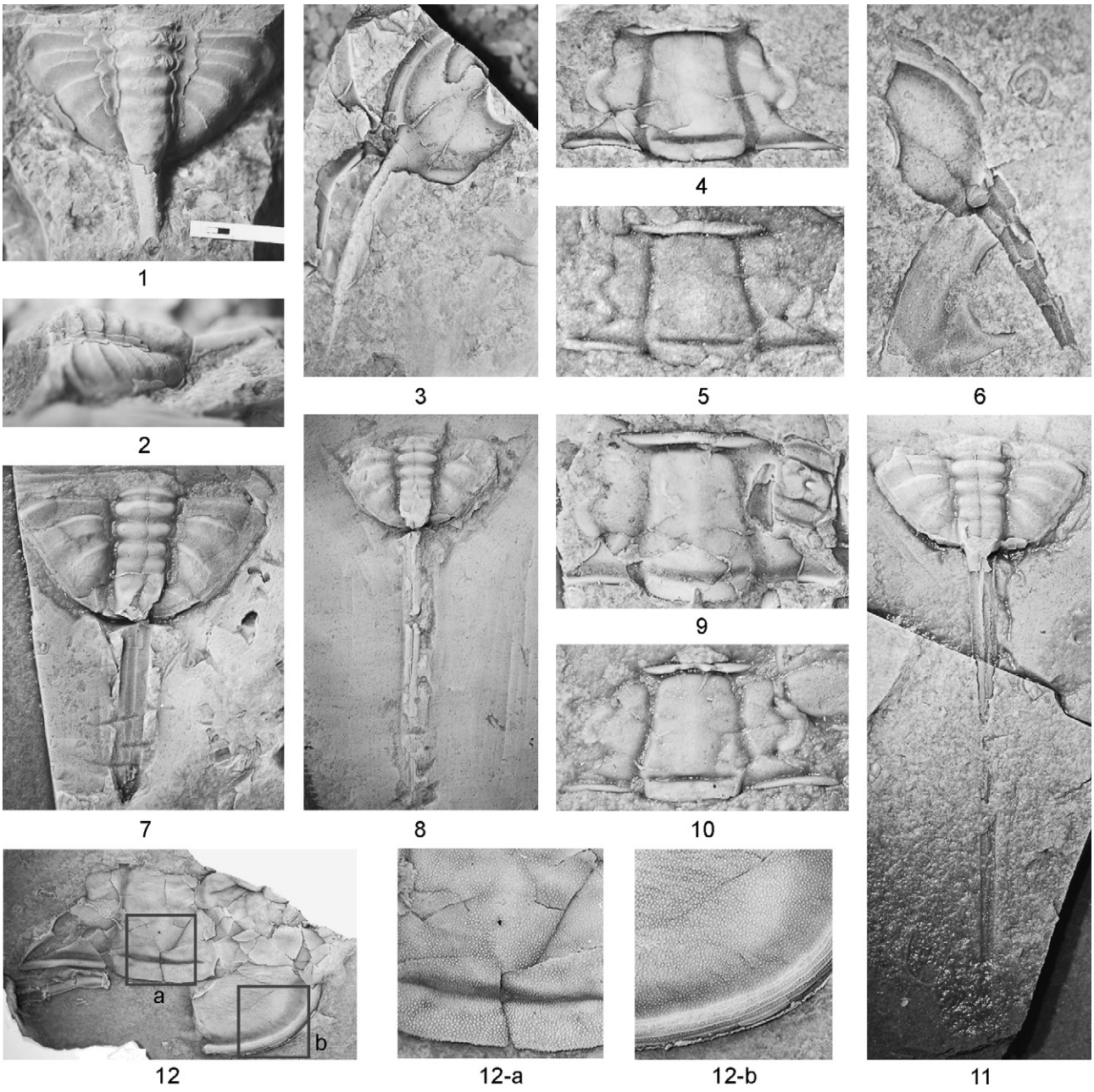

Fig. 16. **1–12**. *Eochuangia hana* Kobayashi, 1935. All of the specimens are preserved as internal moulds, unless otherwise stated. **1** PA1053, incomplete pygidium, × 2; **2** Lateral view of PA1053, × 2; **3** SNUP 929, librigena, × 3.2; **4** SNUP 930, cranidium, × 5.5; **5** SNUP 931, cranidium × 4; **6** SNUP 932, librigena, × 5; **7** SNUP 933, pygidium, × 2; **8** SNUP 934, pygidium, × 3.5; **9** SNUP 935, cranidium, × 5.2; **10** SNUP 936, cranidium, × 5.5; **11** SNUP 937, pygidium, × 3; **12** SNUP 938, latex cast of external mould of incomplete cranidium and librigena, × 2.5. Note densely-paced fine granules on the surface of glabella (12a, × 7) and librigena (12b, × 7).

type species and thus are treated as junior synonyms of *H. longus*. The holotype cranidium of *H. concavus* appears to represent a transversely compressed form of *H. longus*. Examination of the specimens referred to *P.* (*Kogenium*) *rotundum* Kobayashi, 1935 by Kobayashi (1962) also reveals that some cranidia show the morphological characteristics of, and hence are transferred to, *H. longus*. On the other hand, *H. tenuis* was transferred to *Proceratopyge* by Lee and Choi (1995) based on the cranidial morphological features. The holotype cranidium of *H.? puteolatus* also displays characteristic features of *Proceratopyge*, such as well-defined glabellar furrows and paradoublural lines, and thus should be transferred to the genus, while the supposedly associated pygidia cannot be accommodated with *Proceratopyge*.

The present collection comprises a number of cranidia and pygidia representing various ontogenetic stages. The most notable morphological changes in cranidia are observed in the frontal area and palpebral lobes. The frontal area in smaller cranidia is differentiated into frontal field and anterior border, whereas it is undifferentiated in larger specimens. In addition, the bivariate plots of the ratios of frontal area length:cranidial length against cranidial length [Fig. 10(1)] show that the frontal

area becomes comparatively longer with growth: the ratios of smaller forms range from 0.15 to 0.35, while the larger cranidia have higher ratios of 0.4 to 0.45. In contrast, the relative length of palpebral lobes steadily decreases with growth [Fig. 10(2)]: the smaller forms (less than 10 mm in length) have comparatively larger palpebral lobes, ranging from 0.25 to 0.45 in the ratios of palpebral lobe length:cranidial length, whereas the larger specimens have smaller palpebral lobes with the ratios of 0.2 to 0.25. Pygidia also display a range of ontogenetic variation in overall outline, direction of interpleural furrows, and breadth of border and doublure. The juvenile pygidia have a semicircular outline, anterior two to three interpleural furrows directed transversely, and very narrow border and doublure. With growth, pygidia become more transverse in outline [Fig. 10(3)] and have diagonally directed interpleural furrows and very broad border and doublure. The ratios of border width:pygidial length in juvenile forms range from less than 0.1 to 0.3, while those of larger specimens normally exceed 0.4 [Fig. 10(4)].

Genus ***Pseudoyuepingia*** Chien, 1961

Type-species: *Pseudoyuepingia modesta* Chien, 1961 from the Furongian of Guizhou, China (by original designation).

Remarks: as suggested in the generic remarks of *Haniwoides*, *Pseudoyuepingia* may be phylogenetically related to *Haniwoides*. Peng et al., (2004) differentiated *Pseudoyuepingia laochatianensis* Yang in Zhou et al., 1977 from *P. modesta* in bearing a plectrum in cranidium, larger and posteriorly located palpebral lobes, and transverse posterior branch of facial suture. In these respects, *P. laochatianensis* can be referred to *Aplotaspis* Henderson, 1976. Although *Aplotaspis* has been suggested to be a junior synonym of *Haniwoides* (by Shergold, 1982) or *Pseudoyuepingia* (by Peng et al., 2004), it is considered that the cranidium with a plectrum has a generic significance. In addition, *Aplotaspis* was reported to occur mainly in the lower Furongian strata of Australia (Henderson, 1976; Shergold, 1982).

Pseudoyuepingia asaphoides (Kobayashi, 1962)

Fig. 11(1–9)

1962. *Iwayaspis asaphoides* – Kobayashi, p. 122, Pl. 6, Figs. 1–10; Pl. 8, Fig. 24; Pl. 9, Fig. 24.

1996. *P. asaphoides* (Kobayashi) – Lee and Choi, p. 156, Pl. 3, Figs. 1–6; Pl. 4, Figs. 1–5.

Material, horizon, and locality: six cranidia and 13 pygidia; *P. asaphoides* Zone of the Machari Formation; units KG-47 to KG-91 of the Konggiri section, Yongwol.

Remarks: *P. asaphoides* (Kobayashi, 1962) has been described in detail by Lee and Choi (1996).

Superfamily TRINUCLEOIDEA Swinnerton, 1915

Family ALSATASPIDIDAE Turner, 1940

Genus ***Joshuaspis*** nov. gen.

Etymology: referring the forwardly-divergent eye ridges which mimic the branches of the Joshua tree.

Type-species: *J. parvus* nov. sp. from the *E. hana* Zone of the Machari Formation, Yongwol, Korea.

Diagnosis: a small alsataspid having semi-elliptical cranidium with parallel-sided or forward-tapering narrow glabella, flat to concave preglabellar field, semi-elliptical occipital ring with median node and transverse ridge-like anterior border, and forwardly divergent eye ridges.

Remarks: *Joshuaspis* nov. gen. bears a superficial resemblance to *Ajrikina* Kryskov in Borovikov and Kryskov, 1963 and *Jegorovaia* Lu in Wang, 1964 in overall cranidial outline and arrangement of eye ridges. *Ajrikina* from the Middle Cambrian to Furongian of South China and Kazakhstan differs in having medially thickened anterior cranidial border, while *Jegorovaia* from the Furongian of South China and Kazakhstan is easily differentiated from *Joshuaspis* in having a forwardly expanding glabella, a convex preglabellar field with a plectrum, a broadly rounded and thickened anterior border, and a pair of long carinae behind the palpebral lobes.

Some of the Chinese species referred to *Jegorovaia* clearly display the morphological features of *Joshuaspis* diagnosed above and thus are transferred to the genus. They are *J. areolosa* Zhang in Qiu et al., 1983 from the Qingkeng Formation (Furongian) of Anhui province, China and *J.? jiangjungouensis* Xiang and Zhang, 1985 from the Jiangjungouen Formation (*Glyptagnostus reticulatus* Zone; Furongian) of Xinjiang, China.

Joshuaspis parvus nov. sp.

Fig. 12(1–16)

Etymology: from *parvus*, small; referring to the small size of the cranidia.

Material, horizon and locality: holotype incomplete cephalon, SNUP 900 [Fig. 12(10)]; paratypes SNUP 791, 891–899, 901–905; more than 100 cranidia and two pygidia; *E. hana* Zone of the Machari Formation; units KG-6 to KG-16 of the Konggiri section, Yongwol.

Description: cranidium semi-elliptical in plan view, twice as wide as long. Glabella truncato-conical, ca. 0.6 and 0.25 of cranidial length and width, widest at glabellar base, tapering steadily forward, with broadly truncated glabellar front; two or three pairs of lateral glabellar furrows; S1 and S2 deeply incised, connected to axial furrows; S3 pit-like, faintly indicated. LO semi-elliptical, wider than glabellar base, ca. one-third of glabellar length, with stout medial node; SO transverse, clearly incised. Anterior border ridge-like, weakly convex forward to transverse. Preglabellar area flat, but medially depressed. Eye ridges thin, simple, emerging from antero-lateral corners of glabella and diverging strongly forwards. Palpebral lobes small, bulb-like, located at level of glabellar front. Facial suture opisthoparian; anterior branch of facial suture convergent, straight; posterior branch of facial suture long, divergent convex. Posterior border narrow; posterior border furrow deep, broadens abaxially. Librigena with narrow and gently convex genal field; lateral border narrow in anterior half, becoming broader; lateral border furrow clearly incised in anterior half, but indistinct in posterior half; genal corner prolonged rearward to form moderately long genal spine. Surface sparsely granulate.

Remarks: the present collection displays a range of ontogenetic and taphonomic variation. The smallest specimen available is 1.4 mm long and 2.0 mm wide. The smaller specimens have a narrower glabella, while the larger ones have

a broader glabella. This species bears some resemblance to *J. areolosa* (Zhang in Qiu et al., 1983), which is however characterized by a parallel-sided glabella and a more densely granulate surface sculpture. *Joshuaspis jiangjungouensis* (Xiang and Zhang, 1985) differs from *J. parvus* in having a parallel-sided glabella with four pairs of lateral glabellar furrows, a concave anterior cranidial border, and a densely granulate prosopon. Two very small pygidia assignable to this species are recognized, but their preservation is insufficient to describe morphological details.

Genus ***Macharia*** nov. gen.

Etymology: after the Machari Formation from which this genus was recovered.

Type-species: *M. pengi* nov. sp. from the *E. hana* Zone of the Machari Formation, Yongwol, Korea.

Diagnosis: a small alsataspid having a subtrapezoidal cranidium with ovoid glabella, strap-like occipital ring without node, flat to concave preglabellar field, and transverse ridge-like anterior border, and transverse eye ridges.

Remarks: *Macharia* nov. gen. shows some resemblance in overall cranidial morphology to *Rhadinopleura* Harrington and Leanza, 1957 from the Furongian to Lower Ordovician of Argentina, which is distinguished by convex preglabellar area, a broadly rounded anterior cranidial margin, and an undifferentiated preglabellar area. This genus may also be comparable to *Joshuaspis* nov. gen., but is distinct from the latter in having an ovoid glabella, transverse eye ridges, and transverse anterior cranidial margin.

Macharia pengi nov. sp.

Fig. 13(1–8)

Etymology: after Prof. Shanchi Peng in recognition of his contribution to the study of Cambrian trilobites.

Material, horizon and locality: holotype cephalon, SNUP 906 [Fig. 13(1)]; paratypes SNUP 907–913; nine cranidia; *E. hana* Zone of the Machari Formation; units KG-9 to KG-12 of the Konggiri section, Yongwol.

Description: cranidium subtrapezoidal in plan view, two to three times wider than long. Glabella convex, ovoid in outline, ca. 0.7 and 0.3 of cranidial length and width, widest at glabellar mid-length; three pairs of glabellar furrows distinct; S1 and S2 deeply incised, connecting to axial furrows; S1 convex, directed obliquely rearwards; S2 transverse; S3 pit-like. LO strap-like, wider than glabellar base, one-fifth of glabellar length without node; SO composite, clearly incised. Anterior border ridge-like, transverse, one-half of maximum cranidial width. Preglabellar field concave, ca. one-tenth of cranidial length; preocular field flat to weakly convex, ca. one-half as long as postocular field; postocular field weakly convex, with a pair of oblique-inward directed shallow depressions emerging rearward from posterior ends of palpebral lobes to about middle of postocular field. Eye ridges thin, simple, transverse. Palpebral lobes small, bulb-like. Facial suture opisthoparian; anterior branch of facial suture convergent straight; posterior branch of facial suture divergent, weakly convex. Posterior border thin; posterior border furrow deep and broad, becoming broader abaxially. Surface densely granulate. Pygidium unknown.

Order PTYCHOPARIIDA Swinnerton, 1915

Superfamily PTYCHOPARIOIDEA Matthew, 1887

Family CHANGSHANIIDAE Kobayashi, 1935

Genus ***Changshania*** Sun, 1924

Type-species: *Changshania conica* Sun, 1924 from the Changshan Formation (Furongian), Hebei province, China (by original designation).

Changshania equalis Sun, 1935

Fig. 14(1–4)

1935. *C. equalis* – Sun, p. 42, Pl. 2, Figs. 8 and 9, 13–17.

1965. *C. equalis* Sun – Lu et al., p. 466, Pl. 92, Figs. 7–10.

1989. *Changshania equalis* Sun – Zhu and Wittke, p. 227, Pl. 10, Fig. 12; Pl. 12, Fig. 8.

1994. *C. equalis* Sun – Qian, p. 74, Pl. 16, Fig. 7; Pl. 17, Fig. 8.

2006. *C. equalis* Sun – Choi and Kim, p. 348, Figs. 3a–d.

Material, horizon and locality: 15 cranidia; *E. hana* Zone of the Machari Formation; units KG-15 to KG-16 of the Konggiri section, Yongwol.

Remarks: this species has been treated comprehensively by Choi and Kim (2006).

Family DOKIMOCEPHALIDAE Kobayashi, 1935

Genus ***Jingxiania*** Chien in Lu et al., 1974

Type-species: *Jingxiania beigongliensis* Chien in Lu et al., 1974 from the Furongian of Anhui province, China (by original designation).

Remarks: Shergold (1980) erected a new subfamily Wuhuiinae to accommodate Australo-Asiatic dokimocephalids with an anteriorly bluntly rounded or truncated glabella, oblique-rearward and bifurcate S1, large palpebral lobes located close to axial furrows, and a transverse subtrapezoidal to semicircular pygidium with two to three segments. Included genera were *Wuhuia* Kobayashi, 1933, *Saimachia* Kobayashi, 1937, and *Lorrettina* Shergold, 1972. Shergold (1982) added *Chalfontia* Shergold, 1982 to the subfamily.

Jingxiania Chien in Lu et al., 1974 was originally placed under the family Uncertain, but later was included within the family Dokimocephalidae by Qian (1985). *Jingxiania* is closely similar to *Wuhuia* Kobayashi, 1933 in cranidial morphology, but associated pygidia are different from the type material of *Wuhuia belus* (Walcott, 1905). Four species of *Jingxiania* were established by Chien in Lu et al. (1974), but Jago (1987) suggested that they might represent a single species.

Jingxiania sp. cf. *J. beigongliensis* Chien in Lu et al., 1974

Fig. 14(5, 6)

Material, horizon and locality: four cranidia; *P. asaphoides* Zone of the Machari Formation; units KG-104 of the Konggiri section, Yongwol.

Remarks: the present material is closely comparable to *Jingxiania beigongliensis* in possessing a truncate-conical glabella, long palpebral lobes located close to the glabella, and a frontal area divided more or less evenly into a convex anterior cranidial border and a preglabellar area. However, poor preservation of the specimens precludes definite assignment to the species.

Genus ***Wuhuia*** Kobayashi, 1933

Type-species: *Solenoparia belus* Walcott, 1905 from the *Tsinania* Zone (Furongian) of Shandong province, China (by original designation).

Remarks: since the establishment of *Wuhuia* in 1933, five species have been assigned to the genus: *Solenoparia belus* Walcott, 1905; *Ptychoparia dryope* Walcott, 1905; *Quadraticephalus* (?) *minus* Endo, 1944; *Wuhuia silex* Shergold, 1980; and *Wuhuia longa* Peng, 1992. They were mainly reported to occur in middle Furongian strata: *Wuhuia belus* and *W. dryope* were documented from the *Tsinania* Zone of Shandong province (Zhang and Jell, 1987); *W. minus* from the *Shirakiella xiaoshiensis* Zone of Liaoning province (Qian, 1994); *W. silex* from the *Peichiashania secunda–Prochuangia glabella* and *Peichiashania tertia–P. quarta* Zones of Queensland, Australia (Shergold, 1980); and *W. longa* from the *Probilacunaspis nasalis–Peichiashania hunanensis* Zone of Hunan province, China (Peng, 1992).

Wuhuia sp.

Fig. 14(7)

Material, horizon and locality: one cranidium; *P. asaphoides* Zone of the Machari Formation; units KG-36 of the Konggiri section, Yongwol.

Remarks: a single incomplete specimen recovered from the lower part of the *P. asaphoides* Zone displays the morphological features of *Wuhuia* such as a bluntly rounded forward-tapering glabella, moderately long palpebral lobes located close to the glabella, a short gently convex preglabellar field, and a well-defined evenly arcuate cranidial border. It may be comparable to *W. dryope* (Walcott, 1905) in having a smooth prosopon.

Family ELVINIDAE Kobayashi, 1935

Genus ***Irvingella*** Ulrich and Resser in Walcott, 1924

Type-species: *I. major* Ulrich and Resser in Walcott, 1924 from the Franconia Formation (Furongian) of Wisconsin, USA.

Remarks: the generic concept and occurrence of *Irvingella* from the Konggiri section has been thoroughly treated by Hong et al. (2003b) and hence is not reiterated in this study. Four species of *Irvingella* occur successively in the Konggiri section of the Machari Formation (Fig. 1): in ascending order *I. megalops* (Kobayashi, 1962), *I. convexa* (Kobayashi, 1935), *I. coreanica* Hong et al., 2003b and *I. major* Ulrich and Resser *in* Walcott, 1924. Hong et al. (2003b) demonstrated that the notable morphological change in the *Irvingella* lineage is the progressive reduction of the preglabellar field and eye ridges: the stratigraphically early forms, such as *I. megalops*, are characterized by the differentiated frontal area and relatively long eye ridges, whereas the younger forms have no preglabellar field and vestigial eye ridges.

Superfamily OLENIOIDEA Burmeister, 1843

Family OLENIDAE Burmeister, 1843

Olenid gen. and sp. indeterminate

Fig. 14(8)

Material, horizon and locality: one cranidium; *P. asaphoides* Zone of the Machari Formation; units KG-44 of the Konggiri section, Yongwol.

Remarks: the single cranidium is poorly preserved, but its glabella displays morphological features of the family Olenidae. The specimen is however insufficient to make any meaningful comparison with preexisting genera.

Order CORYNEXOCHIDA Kobayashi, 1935

Superfamily LEIOSTEGIOIDEA Bradley, 1925

Family LEIOSTEGIIDAE Bradley, 1925

Genus ***Chuangia*** Walcott, 1911

Type-species: *Ptychoparia* (?) *batia* Walcott, 1905 from the Gushan Formation, Shandong province, China (by original designation).

Remarks: the genus *Chuangia* is largely restricted to the Furongian of China, but is also known to occur in Korea (Kobayashi, 1935) and Kashmir (Reed, 1934). There are at least 49 species originally assigned to or later transferred to the genus: that is, *C. austriaca* Yang, 1978; *C. batia* (Walcott, 1905); *C.* (*Leptochuangia*) *benxiensis* Lu and Qian, 1983; *C. buchruckeri* (Lorenz, 1906); *C. carinata* Luo, 1983; *C.* (*Aspidochuangia*) *cata* Lu and Qian, 1983; *C. conica* Endo, 1944; *C. convexa* Sun, 1935; *C. convoluta* Resser and Endo in Endo and Resser, 1937; *C. curvata* Sun, 1935; *C. damujingensis* Luo, 1974; *C.* (*Leptochuangia*) *diversa* Qian, 1994; *C.* (*Aspidochuangia*) *elevata* Qian, 1994; *C. elongata* Luo, 1983; *C. endoi* Resser in Endo and Resser, 1937; *C. erdaogouensis* Qian, 1994; *C. fragmata* Walcott, 1911; *C. frequens* (Dames, 1883); *C. hopeiensis* Resser, 1942; *C. huoluensis* Resser, 1942; *C. kawadai* Kobayashi, 1933; *C. kuantungensis* Resser and Endo in Endo and Resser, 1937; *C. lata* Resser and Endo in Endo and Resser, 1937; *C. laevigata* Schrank, 1974; *C. laticonvexa* Luo, 1983; *C. lipoensis* Luo, 1983; *C.* (*Aspidochuangia*) *longa* Qian, 1994; *C. meridionalis* Mansuy, 1916; *C. minor* Luo, 1983; *C. monkei* (Lorenz, 1906); *C. nais* Walcott, 1911; *C. nitida* Walcott, 1911; *C.* (*Aethochuangia*) *nodula* Qian, 1994; *C.* (*Pterochuangia*) *nobilis* Lu and Qian, 1983; *C. olongblukensis* Chu, 1960; *C. planicaudata* Endo, 1944; *C. puteata* Resser and Endo in Endo and Resser, 1937; *C.*? *subangulata* Reed, 1934; *C. subquadrangulata* Sun, 1935; *C. taihakuensis* Kobayashi, 1935; *C. tawenkouensis* Sun, 1935; *C. tolli* Resser and Endo in Endo and Resser, 1937; *C. transversa* Resser and Endo in Endo and Resser, 1937; *C. transversalis* Kobayashi, 1933; *C. wadapurensis* Reed, 1934; *C. wuanensis* Zhang and Wang, 1985; *C. wulingensis* Yang in Zhou et al., 1977; *C. yuani* Sun, 1935; and *C. zhenanensis* Luo, 1983. Of these, 46 species were established from China, two from Kashmir, and one from Korea.

With so many species for this morphologically simple trilobite group, it seems impractical to differentiate all of these species with clarity. The ontogenetic and taphonomic variations for the members of this group should be explored to solve the problem, based on a large number of collections. A thorough review of *Chuangia* and related genera will eventually prove that too many species have been erected.

Chuangia spp.

Fig. 15(1–13)

Material, horizon, and locality: 26 cranidia, 20 pygidia, and six free cheeks; *E. hana* and *A. orientalis* Zones of the

Machari Formation; units KG-8 to KG-30 of the Konggiri section, Yongwol.

Remarks: specimens referable to *Chuangia* occur sporadically in 18 stratigraphic units of the *E. hana* and *A. orientalis* Zones. They are variably preserved but dominantly flattened dorsoventrally. Cranidia display a range of morphological variability in the glabellar width, degree of glabellar tapering, and course of axial furrows. Pygidia are also variable in the length-width ratios and distinctiveness of axial ring furrows. Internal moulds show more distinct ring furrows and a well-defined narrow doublure, while external moulds have less distinct ring furrows and no differentiated border. They are not readily grouped into appreciable morphological types, as the number of specimens is not sufficient enough to reveal the morphological variability of the population. Accordingly exhaustive taxonomic treatment has not been attempted in this study and all the specimens are left under open nomenclature.

Genus ***Eochuangia*** Kobayashi, 1935

Type-species: *E. hana* Kobayashi, 1935 from the Machari Formation, Yongwol, Korea (by original designation).

Remarks: Kobayashi (1935) erected *Eochuangia* to include the leiostegiid trilobites with a stout terminal axial spine and granulate prosopon. Its cranidia cannot be readily distinguished from those of *Chuangia*. Five species of *Eochuangia* were subsequently established in North China: they are *E. sinensis* Chu, 1960; *E. laevis* Duan, 1966; *E. yihjuensis* Nan, 1976; *E. reflexa* Qian, 1994; and *E. semielliptica* Qian, 1994. Specimens of *E. sinensis* are too fragmentary to compare morphologically with other species. *E. laevis* and *E. reflexa* are characterized by a subtriangular pygidium with smooth pygidial pleural fields and a strongly rearward-tapering pygidial axis and are likely to be con-specific. It is not possible to evaluate *E. yihjuensis* which was erected on a single poorly preserved cranidium. *E. semielliptica* based on two pygidia is distinct in having semi-circular pygidia with effaced pleural fields.

Eochuangia hana Kobayashi, 1935

Fig. 16(1–12)

1935. *E. hana* – Kobayashi, p. 183, Pl. 16, Figs. 10–17.

1935. *E. hana* var. *conica* – Kobayashi, p. 184, Pl. 16, Figs. 7–9.

1962. *E. hana* Kobayashi – Kobayashi, p. 35, Pl. 5, Figs. 15a and b, 16 and 17.

1962. *E. hana conica* Kobayashi – Kobayashi, (pars), p. 35, Pl. 7, Figs. 8 and 9, 11, 14.

1962. *Koptura bispinata* – Kobayashi, (pars), p. 101, Pl. 7, Fig. 5 (only).

1992. *E. hana* Kobayashi – Guo and Zhang, Pl. 2, Figs. 8–12.

Material, horizon, and locality: a pygidium (Kobayashi, 1935: Pl. 16, Figs. 16 and 17) is herein designated as the lectotype [Catalogue and repository number PA1053 of the University Museum, University of Tokyo, Japan; refigured in Fig. 16(1 and 2)]; more than 100 specimens; *E. hana* Zone of the Machari Formation; units KG-2 to KG-16 of the Konggiri section, Yongwol.

Description: cranidium subtrapezoidal in outline. Glabella subtrapezoidal, longer than wide, reaching anterior border; posterior two-thirds rapidly tapering forward; anterior one-third parallel-sided; lateral glabellar furrows indistinct. SO simple, straight, moderately incised; LO of more or less uniform length, as long as glabellar base, slightly bent forward at abaxial ends. Anterior border weakly arched forward, upright, in tightly contact with glabella; anterior cranidial border furrow deep. Fixigenae of uniform width, ca. one-third of glabellar width. Facial suture opisthoparian; anterior branch of facial suture weakly convergent, convex; posterior branch of facial suture strongly divergent, sinuous. Palpebral lobes crescentic, moderate in size, ca. one-third of glabellar-occipital length, located at glabellar mid-length. Posterior border thread-like, two-thirds of maximum glabellar width, clearly defined by broad border furrow. Librigena with broad and gently convex genal field; lateral border of uniform breadth, clearly defined by broad border furrow; genal corner prolonged outward and rearward into very long and stout genal spine; eye socle slightly elevated. Surface finely granulate.

Pygidium excluding terminal spine semicircular in outline, twice as wide as long. Axis convex, cylindrical, tapering gently rearwards, one-fourth of pygidial width, consisting of four short axial rings divided by clearly incised axial furrows and a large terminal piece prolonged beyond border to form an upturned, very long (up to three times of maximum length of pleural field) spine. Pleural fields less convex, down-sloping distally; first two or three pleural furrows broad and deep; interpleural furrows shallow; area between pleural and interpleural furrows ridge-like. Border narrow and flat, indicated by change in slope rather than border furrow. Surface finely granulate.

Remarks: this species is fully described herein, because it has been poorly known and seldom documented since its establishment. *E. hana* is distinguished from other species by its broadly furrowed pleural fields and a very long terminal axial spine. Kobayashi (1935) differentiated *E. hana* var. *conica* from *E. hana* by conical outline of the glabella, but the difference is so subtle that the two morphotypes cannot be objectively distinguished from each other. A free cheek referred to *Koptura bispinata* by Kobayashi (1962) is identical to those associated frequently with *E. hana* in the present collection.

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