Two middle Cambrian trilobite genera, *Cyclolorenzella* Kobayashi, 1960 and *Jiulongshania* gen. nov., from Korea and China

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Cyclolorenzella is an important member of the middle Cambrian trilobite faunas in China and Korea. Morphometric analysis based on well-preserved new material assignable to *Cyclolorenzella* from China and Korea reveals that most of the species assigned previously to *Cyclolorenzella* in China are morphologically distinct from the genotype. Accordingly, the new genus *Jiulongshania*, with *J. acalle* (Walcott, 1905) as type species, is proposed to accommodate the following species: *J. acalle*, *J. regularis* (Walcott, 1906), *J. rotundata* (Resser & Endo in Endo & Resser, 1937), *J. longispina* (Wittke & Zhu in Zhu & Wittke, 1989), *J. acuta* (Duan in Duan *et al*., 2005) and *J. longa* sp. nov. Species tentatively transferred to *Jiulongshania* are *J.*? *subcylindrica* (Chu, 1959), *J.*? *yentaiensis* (Chu, 1959), *J.*? *humilis* (Zhang in Qiu *et al*., 1983), and *J.*? *latisulcata* (Zhang in Qiu *et al*., 1983). This taxonomic revision results in only two species remaining in *Cyclolorenzella*, the type species *C. quadrata* (Kobayashi, 1935) and *C. convexa* (Resser & Endo in Endo & Resser, 1937). *Jiulongshania* has a relatively long stratigraphic range from the *Damesella–Yabeia* Zone to the *Blackwelderia* Zone of China, whereas *Cyclolorenzella* is restricted to the stratigraphically younger *Drepanura* Zone in China and Korea.

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THE CAMBRIAN trilobite genus *Cyclolorenzella* was erected by Kobayashi (1960) with the type species, *Lorenzella quadrata* Kobayashi, 1935, from the *Drepanura* Zone of the Sesong Formation, Korea. Subsequently, more than 20 species have been assigned to *Cyclolorenzella* from the upper middle Cambrian strata of China (Kobayashi 1960, Lu *et al*. 1965, Yang 1978, Qiu *et al*. 1983, Zhu & Wittke 1989) and Korea (Hong *et al*. 2003). *Cyclolorenzella* was also documented less convincingly from Kashmir (Jell 1986) and England (Rushton 1978). Species of *Cyclolorenzella* described from Vietnam and South China (Kobayashi 1960, Yang 1978) appear to be better assigned to *Torifera* (cf. Peng *et al*. 2004).

Although many species have been referred to *Cyclolorenzella*, the relatively simple morphology of these trilobites has hampered not only species-level assignment within the genus but also correct identification of the genus as a whole. Examination of the type material of *Cyclolorenzella quadrata* and new collections from Korea and North China (Fig. 1) demonstrates that most of the Chinese species assigned formerly to *Cyclolorenzella* are morphologically distinct from the type species. Accordingly, this study attempts to analyze the morphological disparity among *Cyclolorenzella* and related forms based on new material from the Sesong Formation of

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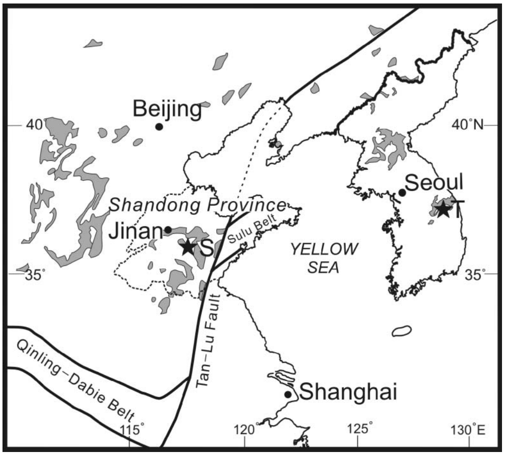


Fig. 1. Locality map. Stars with 'S' and 'T' indicate the locations of Jiulongshan section in the Luxi (western Shandong) Block, Shandong Province, China and Jikdong section in the Taebaeksan Basin, Korea, respectively. Shaded areas represent the Cambrian–Ordovician exposures.

Korea and the Kushan Formation of Shandong Province, China where many species of *Cyclolorenzella* have been documented (Walcott 1913, Zhang & Jell 1987). The results of a morphometric analysis provide a basis for the erection of a new genus, *Jiulongshania*, and for a refined generic concept of *Cyclolorenzella*.

Fossil localities and material

Jikdong section at the Taebaeksan Basin, Korea

The type material of *Cyclolorenzella quadrata* was collected from the Sesong Formation at the Jikdong (Shoku-do) section, Korea, where the Cambrian strata are relatively well exposed (Kobayashi 1935, 1960). The Jikdong section (128°47′05″E, 37°10′16″N) is located along a narrow valley in the Taebaeksan Basin (Fig. 1) and comprises a nearly complete succession of the lower Palaeozoic Taebaek Group. The Taebaek Group is a mixed siliciclastic–carbonate succession and comprises, in ascending order, the Jangsan/Myeonsan, Myobong, Daegi, Sesong, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan, and Duwibong formations (Kobayashi 1966, Choi & Chough 2005). The Cambrian–Ordovician boundary was suggested to lie within the lower part of the Dongjeom Formation (Choi *et al.* 2003). The Sesong Formation comprises dominantly shale and sandstone with sporadic intercalations of thin limestone conglomerate and grainstone beds (Kobayashi 1966). However, the fossiliferous lower part of the formation in the Jikdong section is characterized by alternations of shale, limestone-shale couplets, and limestone conglomerate facies.

Fossils are generally scarce in this unit, but poorly preserved trilobites such as *Cyclolorenzella*, *Drepanura*, *Blackwelderia*, *Bergeronites*, and some agnostoids have been found in several fossiliferous beds. The trilobite assemblage indicates that the sampled interval belongs to the *Drepanura* Zone (cf. Kobayashi 1966). To obtain better specimens, limestone blocks within the interval were dissolved by hydrochloric acid, the residues producing comparatively well-preserved trilobite specimens. Acid-resistant sclerites referable to *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser 1937) were recovered from four horizons of the Sesong Formation and include cranidia, pygidia, librigenae, and thoracic segments representing a range of ontogentic stages.

Jiulongshan section at Shandong Province, China

The Jiulongshan section (117°44′35″E, 36°48′42″N) is located along a mountain trail near Gangcheng in the western part of Shandong Province, within the so-called Luxi (western Shandong) Block, which is bounded to the east by the Tan-Lu Fault

(Fig. 1). Strata of the Luxi Block have long been employed as a stratigraphic standard for the middle Cambrian to Furongian (or upper Cambrian) of North China (Zhang & Zhu 2000). The Cambrian succession of the area consists of, in ascending order, the Liguan, Zhushadong, Manto, Changhia, Kushan, and Chaumitien formations (Zhang 1996).

The Kushan Formation is characterized by the predominance of shale in the lower part and limestone in the upper part. The Kushan Formation in the Jiulongshan section reaches *ca* 110 m thick, and is almost twice the thickness of the type section at Zhangxia where the formation is only 62 m thick. The Kushan Formation in the Jiulongshan section is composed largely of shale with sporadic calcareous nodules, limestone conglomerate, and bioclastic wackestone. The lower part (*ca* 31 m thick) is composed dominantly of shales containing calcareous nodules interbedded with lime mudstones. The middle part (*ca* 34 m thick) is an alternating succession of shales with calcareous nodules and limestone conglomerates. The upper part (*ca* 45 m thick) is a thick succession of bioclastic wackestones and limestone-shale couplets.

The Kushan Formation contains two trilobite zones, the *Blackwelderia* and *Drepanura* zones, in the Luxi Block (Lu & Dong 1953, Zhang & Jell 1987). In the Jiulongshan section, the *Blackwelderia* Zone (corresponding to about the bottom 95 m of the formation) yields *Ammagnostus*, *Kormagnostus*, *Damesella*, *Blackwelderia*, *Teinistion*, *Monkaspis*, *Bergeronites*, and *Liostracina*, whereas the *Drepanura* Zone (*ca* upper 15 m) includes *Pseudagnostus*, *Utagnostus*, *Clavagnostus*, *Kormagnostus*, *Drepanura*, *Stephanocare*, *Blackwelderia*, *Teinistion*, and *Liostracina*.

Several hundred specimens referable to *Cyclolorenzella* were recovered from 36 beds of the Kushan Formation in the Jiulongshan section. Specimens in shale are generally flattened or fragmented, whereas those in limestone are complete and retain their original convexity. Consequently, a total of 66 specimens from 25 horizons of the limestone facies were used for quantitative analysis in this study. Those specimens preserved in shale were used to confirm the stratigraphic occurrence of the studied taxa.

Morphometric analysis

Seventy-three cranidia (66 from the Jiulongshan section, China and seven from the Jikdong section, Korea) were selected for morphometric analysis. In general, they are small (1.5–5 mm in cranidial length), and their morphological differences are subtle. Acid-resistant specimens from Korea were examined by scanning electron microscopy. All of the cranidia from China were examined using a stereomicroscope, and the sclerite dimensions were measured using an image-analysis system, which allows measurement of specimens to micrometres. Pygidia from China are generally very small and were studied by scanning electron microscopy.

Principal-component analysis (PCA), which has been frequently used for assessment of morphological variation of trilobites (Hughes 1994, Paterson 2005), was employed to examine the morphological disparity among the specimens. PCA provides a means of transforming a large quantity of data into a small number of principal components of variation. In general, principal components with eigenvalues greater than 1 are considered significant. Theoretically, principal components define a multi-dimensional space in which measurements of the specimens can be plotted. The two-dimensional scatter plots for significant principal components provide a graphical presentation of morphological variation for the population.

Measurements

Eleven parameters were measured for morphometric analysis (Fig. 2): i.e. A1 for total cranidial length; B for total glabellar length (excluding the occipital ring); C for exsagittal palpebral lobe length; D5 for occipital post-palpebral distance; D7 for pre-cranidial pre-palpebral distance; E for sagittal length of occipital ring (excluding the occipital spine); F1 for length of cranidial frontal area; J for palpebral cranidial width; J1 for posterior cranidial width; K2 for maximum glabellar width; and K5 for anterior glabellar width. Abbreviations for parameters are quoted from Shaw (1957). Measurements of 11 parameters for 73 cranidia are provided in Appendix 1. These parameters were used for generating non-dimensional variables to minimize the size effect, and 11 variables were selected: J/A1, F1/A1, B/A1, E/A1, C/A1, D5/A1, D7/A1, K2/B, J1/J, K2/J, and K5/J. Calculation of these variables for 73 cranidia forms a large data matrix (73 × 11). This matrix has been analyzed using the software PAST version 1.49 (Hammer *et al.* 2001).

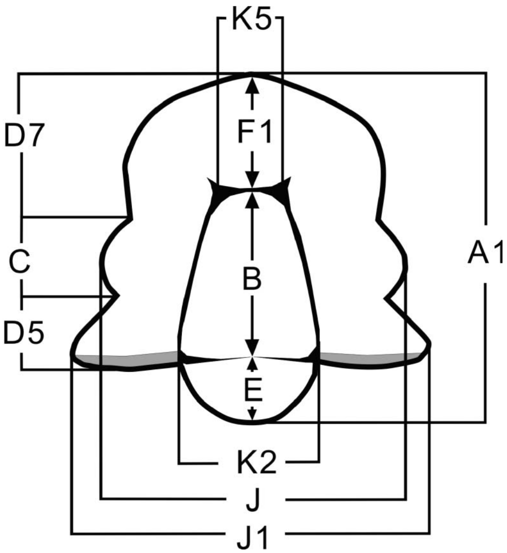


Fig. 2. Linear dimensions measured on cranidia of *Cyclolorenzella* and *Jiulongshania* gen. nov. Abbreviations are the same as those in Shaw (1957).

Results

Principal-component analysis shows an interesting result, in which two clearly distinct morphotype groups are recognized (Fig. 3). The first three components (with eigenvectors greater than 1) account for 74.75% of the variance (Tables 1 and 2): component 1 (35.36% of the variance) appears to reflect overall cranidial shape (J/A1); component 2 (25.24% of the variance) is most closely related to the relative location of palpebral lobes (D5/A1 and J1/J); and component 3 (14.15% of the variance) is strongly influenced by glabellar shape (K2/B).

In the bivariate plots of the first two components (Fig. 3A), one group forms a large elliptical cluster displaying a considerable morphological variability and includes, exclusively, the specimens from the lower and middle parts (*Blackwelderia* Zone) of the Kushan Formation. The other group occupies a small portion of the morphospace with negative values on component 1 and positive values on component 2, and comprises the specimens referable to *C. convexa* from the *Drepanura* Zone of Korea and China. The absence of transitional morphologies between the two groups is here considered to constitute sufficient distinction to warrant assignment to different genera. The larger group is easily differentiated from the smaller group (grey circle in the upper left of Fig. 3A) by relatively longer cranidia (J/A1 less than 1.2), longer frontal area (F1/A1 greater than 0.25), and broader glabella (K2/J greater than 0.4). As the smaller group comprises exclusively *C. convexa*, a new generic name, *Jiulongshania*, is proposed for the larger group derived from the fossil locality (Jiulongshan section).

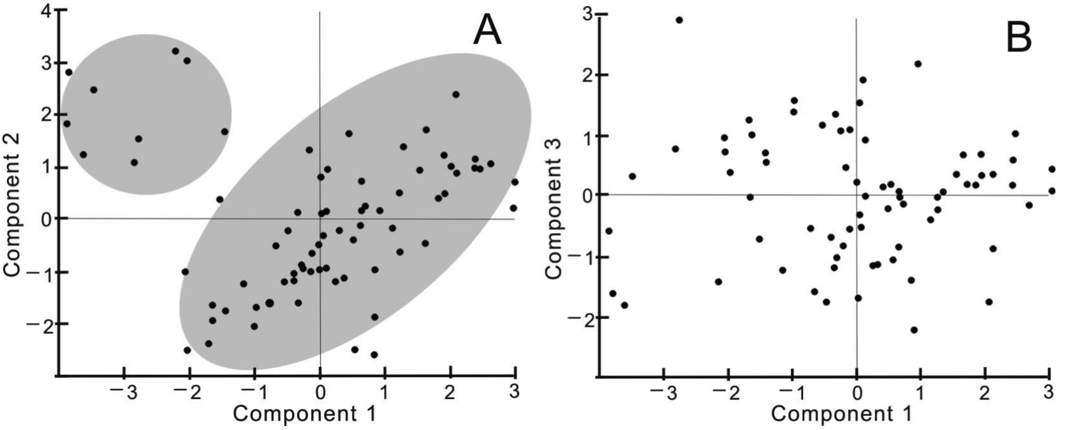


Fig. 3. Scatter plots of the first three principal components for 73 cranidia assignable to *Cyclolorenzella* before taxonomic revision is made. **A**, principal component 1 vs principal component 2. Note the two distinct clusters shaded in gray. **B**, principal component 1 vs principal component 3.

Principal component	Eigen value	Percentage of variance	Cumulative percentage
1	2.692	35.36	35.36
2	1.922	25.24	60.60
3	1.077	14.15	74.75
4	0.619	8.13	82.88
5	0.556	7.30	90.18
6	0.288	3.78	93.96
7	0.261	3.42	97.38
8	0.151	1.98	99.36
9	0.138	0.49	99.85
10	0.010	0.13	99.97
11	0.002	0.02	100.0

Table 1. Eigenvalues and percentage of variance accounted for principal components generated by morphometric analysis of 73 cranidia assignable to *Cyclolorenzella* from the Kushan Formation of the Jiulongshan section, China, and from the Sesong Formation of the Jikdong section, Korea.

Systematic palaeontology

The morphological terms employed here generally follow those of Whittington & Kelly (1997) but our use of the term glabella excludes the occipital ring. All of the specimens described in this paper are stored in the palaeontological collections of Seoul National University, Korea, with registered number under the acronym SNUP.

Order PTYCHOPARIIDA Swinnerton, 1915

Family DICERATOCEPHALIDAE Lu, 1954

Zhang & Jell (1987) assigned *Diceratocephalus* Lu, 1954, *Cyclolorenzella* Kobayashi, 1960, *Aulacodigma* Öpik, 1967, *Torifera* Wolfart, 1974, *Fenghuangella* Yang in Zhou *et al*., 1977, and *Xiangia* Peng, 1987 to Diceratocephalidae. Five more genera added to the family by Jell & Adrain (2003) were *Anopocodia* Öpik, 1967, *Hwangjuella* Kim, 1980, *Jiangnania* Lin & Zhou in Lin *et al*., 1983, *Tangshihlingia* Chu, 1959 and *Tholifrons* Palmer, 1968. However, *Hwangjuella*, *Jiangnania* and *Tholifrons* have morphologies distinct from other members of Diceratocephalidae, whereas *Anopocodia* and *Tangshihlingia* are poorly preserved and described, thus necessitating more information for confident inclusion in this family. Peng *et al*. (2004) suppressed *Xiangia* as a junior synonym of *Torifera* and referred *Torifera* to the family Alsataspididae.

Principal component	1	2	3
J/A1	−0.535	0.088	0.325
F1/A1	0.353	−0.096	0.261
B/A1	−0.352	−0.059	−0.371
E/A1	−0.179	0.216	0.009
C/A1	−0.294	−0.001	−0.116
D5/A1	−0.261	−0.458	−0.136
D7/A1	0.409	0.328	0.142
K2/B	−0.115	−0.372	0.705
J1/J	0.260	−0.459	−0.311
K2/J	0.173	−0.388	−0.110
K5/J	0.033	−0.340	0.176

Table 2. Eigenvectors for variables on the first three principal components produced by morphometric analysis of 73 cranidia assignable to *Cyclolorenzella* from the Kushan Formation of the Jiulongshan section, China, and from the Sesong Formation of the Jikdong section, Korea.

Consequently, the family Diceratocephalidae comprises four genera: *Diceratocephalus*, *Cyclolorenzella*, *Aulacodigma*, and *Fenghuangella*. The new genus *Jiulongshania* is assigned to the family Inouyiidae (see below).

The family Diceratocephalidae has been assigned to the order Ptychopariida (Fortey 1997). However, *Aulacodigma* was described as having a ventral median suture (Öpik 1967); so, too, has *Cyclolorenzella* as shown in this study (see below); this feature being an important synapomorphic character of the Asaphida (Fortey & Chatterton 1988), suggesting that the Diceratocephalidae might be a member of the basal asaphid group.

Cyclolorenzella Kobayashi, 1960 emend.

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

Additional species included. *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser, 1937).

Emended diagnosis. Cranidium wider than long; frontal area short, 20–25% of cranidial length, with a distinctive preglabellar boss outlined by parallel-sided furrows emerging from antero-lateral corners of glabella, not differentiated into preglabellar field and anterior border; glabella slender, 30–40% of palpebral cranidial width, with obsolete glabellar furrows; occipital ring with a long and stout median spine; palpebral lobes located at glabellar mid-point.

Remarks. Kobayashi (1960) established *Cyclolorenzella* based on *Lorenzella quadrata* Kobayashi, 1935 from the Sesong Formation, Korea, and assigned 11 pre-existing species to the genus, namely: *Agraulos acalle* Walcott, 1905; *A. armata* Walcott, 1906; *A. tonkinensis* Mansuy, 1915; *Lorenzella rotundata* Resser & Endo in Endo & Resser, 1937; *L.* (?) *convexa* Resser & Endo in Endo & Resser, 1937; *L.* (?) *ogurai* Resser & Endo in Endo & Resser, 1937; *L. parabola* Lu, 1957; *L. kushanensis* Chu, 1959; *L. pustulosa* Chu, 1959; *L. subcylindrica* Chu, 1959; and *L. yentaiensis* Chu, 1959. Subsequently, Lu *et al*. (1965) added two species, *Agraulos divi* Walcott, 1905 and *A. regularis* Walcott, 1906, to the genus and transferred *Agraulos armata* to *Lonchinouyia* Chang, 1963. During the last three decades, 13 new species or subspecies of *Cyclolorenzella* were erected in China. They are: *C. paraconvexa* Yang, 1978; *C. caijiapingensis* Yang, 1978; *C. tuma* Yang, 1978; *C. latisulcata* Zhang in Qiu *et al*., 1983; *C. humilis* Zhang in Qiu *et al*., 1983; *C. jishanensis* Zhang & Wang, 1985; *C. magezhuangensis* Zhang & Wang, 1985; *C. matoshanensis* Zhang & Wang, 1985; *C. hebeiensis hebeiensis* Wittke & Zhu in Zhu & Wittke, 1989; *C. hebeiensis tangshanensis* Wittke & Zhu in Zhu & Wittke, 1989; *C. uniforma* Wittke & Zhu in Zhu & Wittke, 1989; *C. longispina* Wittke & Zhu in Zhu & Wittke, 1989; and *C. acuta* Duan in Duan *et al*., 2005.

Re-examination of Kobayashi's type material of *Cyclolorenzella quadrata* and the morphometric analysis (Fig. 3) performed above suggested that all, but *C. convexa*, of the Chinese species assigned to *Cyclolorenzella* should be excluded from the genus. The type specimen of *C. quadrata* housed in the University Museum of the University of Tokyo (Fig. 4T) is poorly preserved and fragmentary but shows a close morphological similarity to *C. convexa* except for its smooth prosopon. The two species may possibly belong to a single species with different modes of preservation, but the synonymization of the two species has not been attempted herein, as we note that *C. quadrata* can be distinguished from *C. convexa* by its smooth, rather than granulate, sculpture. *Cyclolorenzella*, as diagnosed herein, is clearly differentiated from *Jiulongshania* gen. nov. in having a short frontal area with convex preglabellar boss defined by more-or-less parallel-sided furrows.

Geographical occurrence. *Cyclolorenzella* is confined to Korea and North China. *Cyclolorenzella quadrata* is known only in Korea, whereas *C. convexa* has been recovered from the Taebaeksan Basin, Korea (this study), and Liaoning and Shandong provinces, China (Resser & Endo in Endo & Resser 1937, Chu 1959, Guo *et al*. 1996).

There have been some interesting reports under the name of *Cyclolorenzella* from the middle Cambrian of South China (Yang in Zhou *et al*. 1977, Yang 1978), the Himalayan area (Whittington 1986), Kashmir (Jell 1986), and England (Rushton 1978). Of these, the specimens from the Himalayas and South China have been re-assigned to *Torifera* by Jell & Hughes (1997) and Peng *et al*. (2004), respectively. The specimen from England (Rushton 1978) is similar to *Torifera tuma* (Yang in Zhou *et al*., 1977) rather than to *Cyclolorenzella* in having a conical glabella and nearly transverse to oblique-forwardly running eye ridges. Specimens from Kashmir (Jell 1986) are too poorly preserved for definitive attribution, but the presence of fossulae and baccula mentioned in the description suggests they are more like *Torifera* than *Cyclolorenzella*.

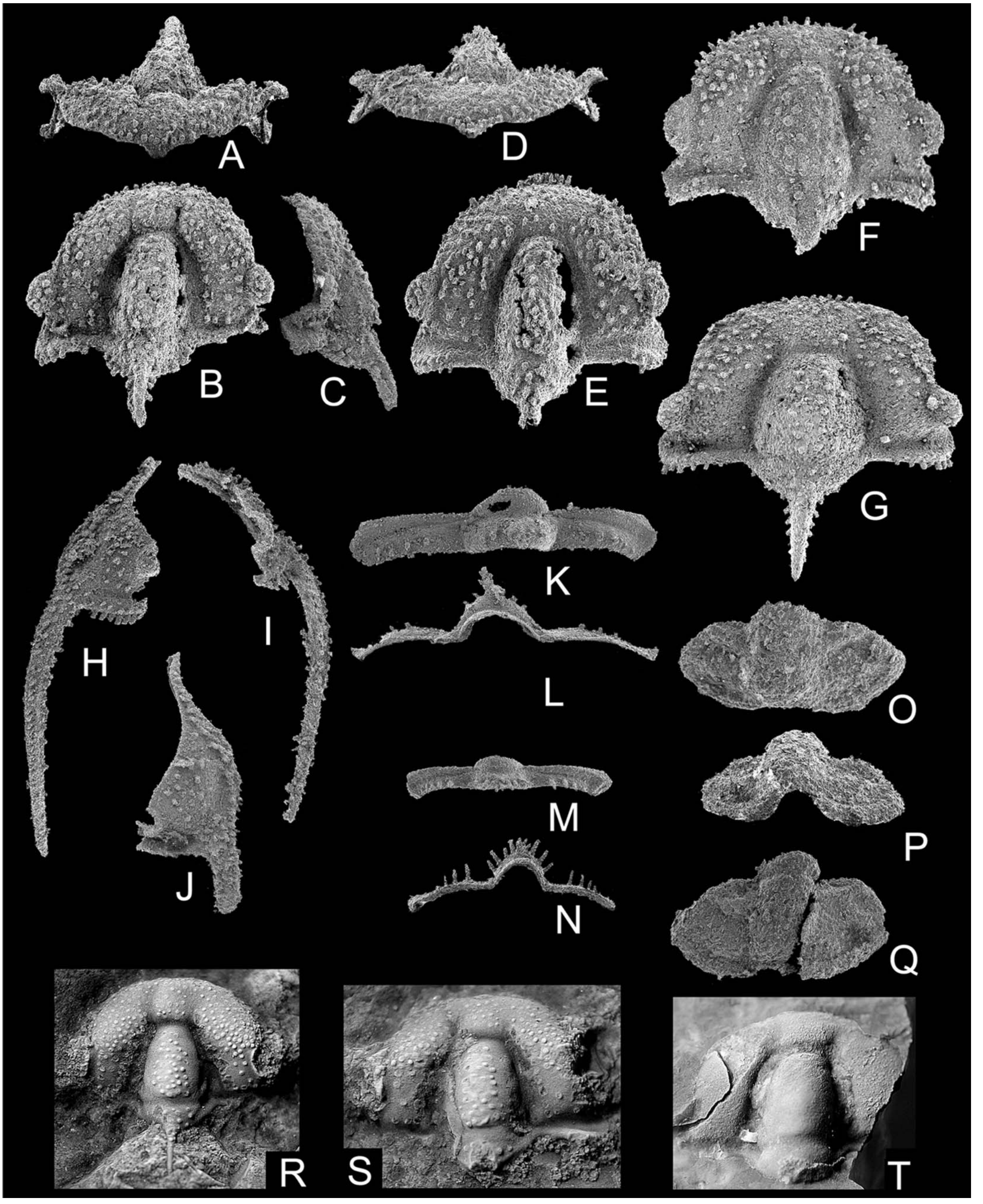
Agraulos tonkinensis from Vietnam was included in *Cyclolorenzella* by Kobayashi (1960), but Wittke (1984) and Fortey (1994) transferred it to *Torifera*. Three species of *Cyclolorenzella* from South China reported by Yang (1978) have been shown, by Peng *et al*. (2004), to be species of either *Torifera* or *Fenghuangella*: *C. paraconvexa* and *C. tuma* were transferred to *Torifera*, and *C. caijiapingensis* to *Fenghuangella*.

Cyclolorenzella convexa (Resser & Endo in Endo & Resser, 1937) (Fig. 4A–S)

1937 *Lorenzella* (?) *convexa* Resser & Endo in Endo & Resser, p. 233, pl. 55, figs 18–19, pl. 65, figs 26–27.
1959 *Lorenzella* (?) *convexa* Resser & Endo in Endo & Resser; Chu, p. 61, pl. 2, fig. 16.
1960 *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser); Kobayashi, p. 389.
1965 (?) *Cyclolorenzella* (?) *convexa* (Resser & Endo in Endo & Resser); Lu *et al*., p. 254, pl. 43, figs 12–15.
1987 *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser); Zhang & Jell, p. 133, pl. 51, fig. 10.
1996 *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser); Guo *et al*., p. 114, pl. 59, fig. 11.

Diagnosis. A species of *Cyclolorenzella* with pustulate prosopon.

Description. Cranidium subtrapezoidal in outline, *ca* 1.2 times wider than long; glabella truncato-conical outlined by deeply incised axial furrows and well-defined preglabellar furrow, about one-half of cranidial length and 0.3–0.4 of cranidial width; glabellar furrows effaced; occipital furrow transverse, shallow; occipital ring semi-circular in plan view, with a long medial occipital spine (Fig. 4G, R); palpebral lobes bean-shaped, located at glabellar mid-point, *ca* one-quarter of cranidial length; eye-ridges obsolete; preglabellar field one-fifth to one-quarter of cranidial length,



with a distinctive boss bounded by a pair of furrows running forward from anterolateral corners of glabella (Fig. 4A, B); anterior branches of facial suture convex and slightly convergent, then sloping ventrally to form an angulate tip pointing downward; posterior branches of facial suture short and slightly divergent backwards. Surface pustulate.

Librigena convex, subtriangular excluding genal spine; border poorly defined; surface ornamented with rod-like tubercles; genal spine *ca* twice as long as cranidial length, running obliquely rearward and then curved inward; doublure moderately wide (Fig. 4I), running ventrally to meet downsloping anterior branch of facial suture (Fig. 4A, D), forming a ventral median suture.

Thoracic segments transverse, slightly curved rearward at distal ends; axis convex, occupying about one-fourth of thoracic width, with an axial spine, ornamented with rod-like tubercles (Fig. 4L, N); pleural field moderately convex; posterior band bearing a row of rod-like tubercles (Fig. 4K, M); pleural furrows clearly incised.

Pygidium subelliptical in outline, twice as wide as long, with medially indented posterior margin (Fig. 4P); axis one-third to one-quarter of pygidial width, with two to three axial rings; border narrow.

Remarks. *Cyclolorenzella convexa* is distinguished from *C. quadrata* by its strongly pustulate prosopon. In the present collection, the smaller specimens have densely spaced rod-like tubercles (Fig. 4B, E, F), but with growth the rod-like tubercles become comparatively shorter to form pustules or granules (Fig. 4G, R, S). The granulate appearance of the type material from Liaoning Province (Endo & Resser 1937) may be due to their larger size (*ca* 10 mm long), whereas smaller specimens on hand (<3 mm long) have stouter and more densely spaced pustules.

Stratigraphic occurrence. Sesong Formation, Jikdong section, Taebaeksan Basin, Korea; approximately 106 m above the base of the Kushan Formation in the Jiulongshan section, Shandong Province, China. Both fossil localities belong to the upper part of the *Drepanura* Zone. Associated trilobite genera include *Drepanura*, *Blackwelderia*, *Teinistion*, *Stephanocare*, *Liostracina*, *Bergeronites*, *Kormagnostus*, and *Clavagnostus*.

Family INOUYIIDAE Chang, 1963

Kobayashi (1960) originally assigned *Cyclolorenzella* to the Agraulidae, but Chang (1963) erected a new family Inoyuiidae to include *Cyclolorenzella* and three other genera. *Cyclolorenzella* was later re-assigned to the Diceratocephalidae by Zhang & Jell (1987), which was accepted by Guo *et al*. (1996) and Jell & Adrain (2003). On

Fig. 4. *Cyclolorenzella convexa* (Resser & Endo in Endo & Resser, 1937) and *Cyclolorenzella quadrata* (Kobayashi, 1935) from Korea and China. **A–Q**, *Cyclolorenzella convexa* recovered from the dissolved residues of limestone samples from about 15 m above the base of the Sesong Formation, Jikdong section, Korea. **A–C**, anterior, dorsal and lateral views of cranidium, SNUP4501, ×16. **D–E**, anterior and dorsal views of cranidium, SNUP4502, ×13.6. **F**, almost complete cranidium with damaged occipital spine, SNUP4503, ×12.3. **G**, complete cranidium, SNUP4504, ×12.3. **H**, oblique lateral view of librigena, SNUP4508, ×11.3. **I**, dorsal view of librigena, SNUP4509, ×12.2. **J**, oblique anterior view of librigena, SNUP4510, ×10.7. **K–L**, dorsal and anterior views of thoracic segment, SNUP4511, ×6.3. **M–N**, dorsal and anterior views of small thoracic segment showing prominent rod-like tubercles, SNUP4512, ×13.4. **O–P**, dorsal and posterior views of pygidium, SNUP4513, ×21.3. **Q**, pygidium, SNUP4514, ×13.6. **R–S**, *Cyclolorenzella convexa* from about 105 m above the base of the Kushan Formation, Jiulongshan section, China. **R**, nearly complete cranidium showing a long occipital spine, SNUP5001, ×7.3. **S**, cranidium, SNUP5002, ×8.4. **T**, holotype cranidium of *Cyclolorenzella quadrata* from the Sesong Formation, Korea, stored in the University Museum, University of Tokyo, Japan, PA1087, ×3.6.

the other hand, Zhu & Wittke (1989) and Duan *et al.* (2005) placed *Cyclolorenzella* under the family Inouyiidae. *Cyclolorenzella* as redefined herein belongs to the Diceratocephalidae, whereas *Jiulongshania* gen. nov. can be better accommodated within the family Inouyiidae based on the morphologic similarity to other inouyiid trilobites.

Jiulongshania gen. nov.

Type species. *Agraulos acalle* Walcott, 1905 from the Kushan Formation (middle Cambrian), Yanzhuang, Shandong Province, China.

Etymology. After the fossil locality, Jiulongshan, from which many specimens assigned to the genus were collected.

Diagnosis. Cranidium generally as long as wide; glabella truncato-conical with faintly impressed glabellar furrows; occipital ring semi-circular, with a small median node; palpebral lobes crescentic, small to intermediate in size, located at a level corresponding to anterior half of glabella; eye-ridges weakly to clearly developed, transverse to directed obliquely rearwards; preglabellar area convex, *ca* one-third of cranidial length; a pair of incomplete furrows emerge from antero-lateral corners of glabella and diverge obliquely forwards on frontal area; anterior border absent or very narrow. Librigena long and narrow, with a postero-laterally directed long genal spine. Pygidium small, micropygous, transversely elliptical in outline; axis one-quarter to one-third of pygidial width, nearly reaching to posterior margin, with four to five axial rings and a terminal piece; border narrow or undeveloped.

Species included. Most of the species formerly assigned to *Cyclolorenzella* in China are referable to this genus. The following six species are included in *Jiulongshania* with confidence: *J. acalle* (Walcott, 1905); *J. regularis* (Walcott, 1906); *J. rotundata* (Resser & Endo in Endo & Resser, 1937); *J. longispina* (Wittke & Zhu in Zhu & Wittke, 1989); *J. acuta* (Duan in Duan *et al.*, 2005); and *J. longa* sp. nov. The species below are provisionally transferred to the genus, but their descriptions and poor quality of illustrations do not allow the morphological features to be clearly determined: *J. subcylindrica* (Chu, 1959); *J. yentaiensis* (Chu, 1959); *J. humilis* (Zhang in Qiu *et al.*, 1983); and *J. latisulcata* (Zhang in Qiu *et al.*, 1983).

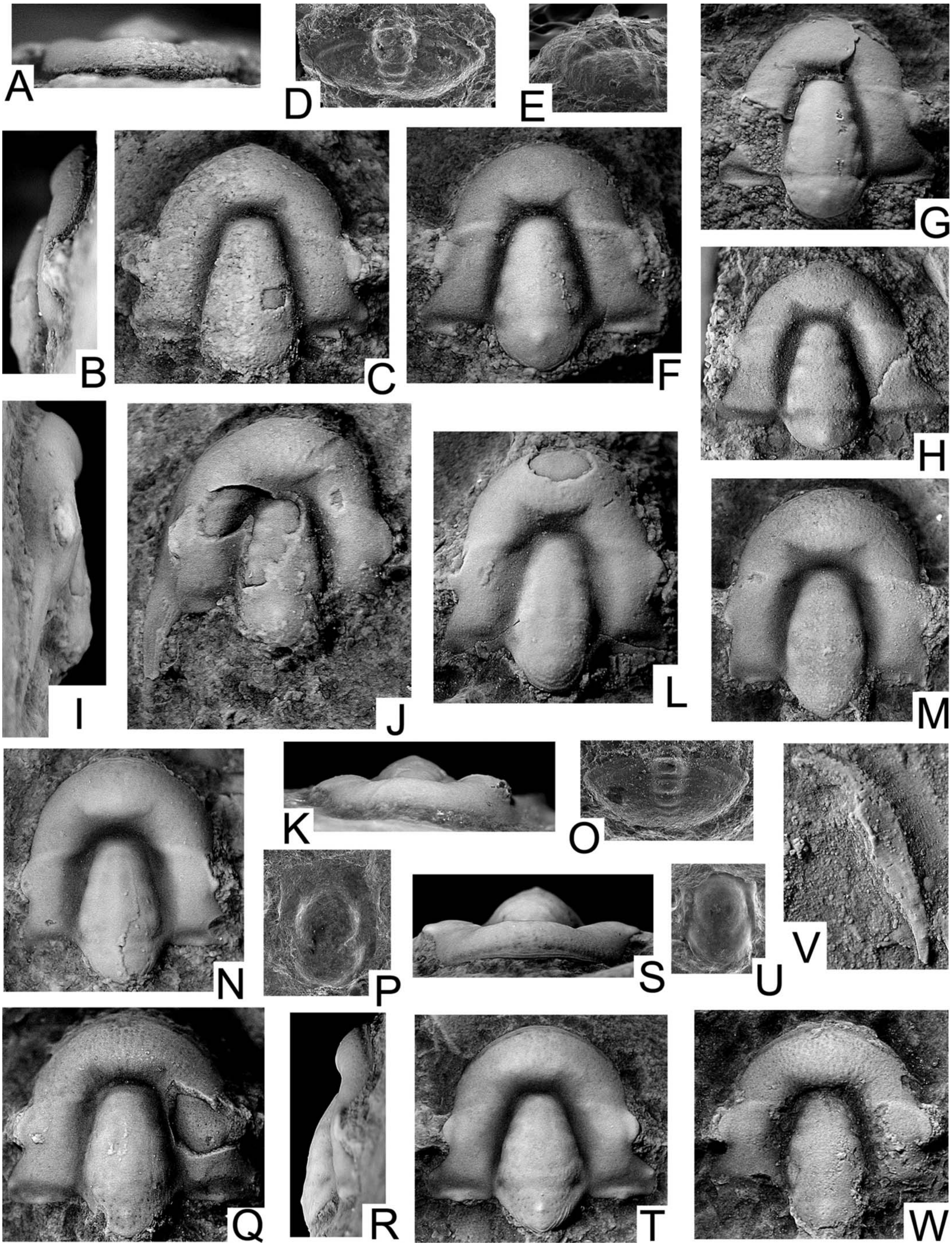
Jiulongshania acalle (Walcott, 1905) (Fig. 5A–W)

1905 *Agraulos acalle* Walcott, p. 43.
1913 *Inouyia*? *acalle* (Walcott); Walcott, p. 150, pl. 14, fig. 15.
1937 *Lorenzella* (?) *ogurai* Resser & Endo in Endo & Resser, p. 232, pl. 51, figs 17–19.
1959 *Lorenzella kushanensis* Chu, p. 99, pl. 2, figs 14–15.
1960 *Cyclolorenzella acalle* (Walcott); Kobayashi, p. 389.
1960 *Cyclolorenzella ogurai* (Resser & Endo in Endo & Resser); Kobayashi, p. 389.
1965 *Cyclolorenzella acalle* (Walcott); Lu *et al.*, p. 251, pl. 42, figs 16–17.

Fig. 5. Jiulongshania acalle (Walcott, 1905). All from the Kushan Formation, Jiulongshan section, China. **A–H**, *J. acalle* from the interval between 24 m and 33 m above the base of the Kushan Formation. **A–C**, anterior, lateral and dorsal views of cranidium, SNUP5030, ×9.3. **D–E**, dorsal and lateral views of pygidium, SNUP5038, ×37. **F**, cranidium, SNUP5032, ×13. **G**, cranidium, SNUP5031, ×11.7. **H**, cranidium, SNUP5033, ×9. **I–P**, *J. acalle* from the interval between 13 m and 22 m above the base of the Kushan Formation. **I–K**, lateral, dorsal and anterior views of cranidium with an articulated librigena, SNUP5020, ×12.7. **L**, cranidium, SNUP5021, ×15.1. **M**, cranidium, SNUP5024, ×9.5. **N**, cranidium, SNUP5023, ×9.3. **O**, pygidium, SNUP5031, ×28.8. **P**, hypostome, SNUP5040, ×16. **Q–W**, *J. acalle* from the interval between 4 m and 10 m above the base of the Kushan Formation. **Q**, cranidium, SNUP5019, ×9. **R–T**, lateral, anterior and dorsal views of cranidium, SNUP5015, ×8.5. **U**, hypostome, SNUP5041, ×8. **V**, librigena, SNUP5042, ×9.4. **W**, cranidium, SNUP5018, ×9.2.

1965 *Cyclolorenzella*? *ogurai* (Resser & Endo in Endo & Resser); Lu *et al*., p. 255, pl. 43, figs 16–18.

1987 *Cyclolorenzella acalle* (Walcott); Zhang & Jell (*pars*), p. 132, pl. 51, figs 1–4 (*non* figs 5–7).



1989 *Cyclolorenzella hebeiensis hebeiensis* Wittke & Zhu in Zhu & Wittke, p. 214, pl. 5, figs 6–8.
1989 *Cyclolorenzella hebeiensis tangshanensis* Wittke & Zhu in Zhu & Wittke, p. 214, pl. 5, figs 9–12.
1989 *Cyclolorenzella uniforma* Wittke & Zhu in Zhu & Wittke, p. 214, pl. 2, figs 11–12, pl. 5, figs 13–14.
1992 *Cyclolorenzella acalle* (Walcott); Zhu, p. 345, pl. 117, fig. 14.
1996 *Cyclolorenzella acalle* (Walcott); Guo *et al.* (*pars*), p. 114, pl. 59, figs 12–15 (*non* fig. 16).
2001 *Cyclolorenzella acalle* (Walcott); Luo (*pars*), p. 379, pl. 4, fig. 17 (*non* figs 11b, c).

Diagnosis. Cranidium as long as wide; glabella generally 45–50% of cranidial length; frontal area moderately long (30–35% of cranidial length); occipital ring long (20–25% of cranidial length); palpebral lobes small (*ca* 20% of cranidial length); a pair of short furrows on frontal area strongly divergent; anterior branches of facial sutures convergent convex; posterior branches of facial sutures less divergent, straight.

Remarks. This species is characterized by a pair of widely divergent short furrows on the frontal area, convergent anterior branches of facial sutures, and less divergent posterior branches of facial sutures. Fortey & Hughes (1998) briefly discussed the bulbous feature of the preglabellar area of *J. acalle*, but considered it not to be a kind of brood pouch due to the poorly defined nature of the 'boss'-outlining furrows. Terrace lines are clearly impressed on the posterior part of the occipital ring (Fig. 5F, L, T).

The holaspid specimen with an articulated librigena shows that the genal spine projects almost directly backward (Fig. 5I, J). The librigena bears terrace lines on the inner side of the genal spine. The associated hypostomes (Fig. 5P, U) are small, subovate, and divided into an ovoid anterior lobe and a crescentic posterior lobe. Pygidia are very small, transversely elliptical, with four axial rings and a terminal piece. Pleural furrows are weakly impressed.

This species is variable and can be roughly divided into three morphotypes. However, their morphological disparity is gradual and subtle enough not to warrant differentiation into separate species. In general, cranidia from the lower part of their range in the formation (Fig. 5Q, T, W) have poorly defined anterior borders and relatively long occipital rings; those from the middle part (Fig. 5J, L–N) have longer frontal areas; and those from the upper part (Fig. 5C, F–H) have a less bulbous preglabellar boss, larger palpebral lobes and shorter frontal areas than the other two morphotypes.

Stratigraphic occurrence. Interval between 4 m and 33 m above the base of the Kushan Formation in the Jiulongshan section. Associated trilobite genera include *Damesella*, *Teinistion*, *Monkaspis*, and *Ammagnostus*.

Jiulongshania rotundata (Resser & Endo in Endo & Resser, 1937) (Fig. 6A–I)

1937 *Lorenzella rotundata* Resser & Endo in Endo & Resser (*pars*), p. 232, pl. 46, figs 4–6, pl. 61, figs 9–10, (*non* fig. 11).
1957 *Lorenzella parabola* Lu, p. 272, pl. 142, fig. 14.
1959 *Lorenzella parabola* Lu; Chu, p. 96, pl. 1, fig. 35, pl. 2, figs 1–5.
1960 *Cyclolorenzella rotundata* (Resser & Endo in Endo & Resser); Kobayashi, p. 389.
1960 *Cyclolorenzella parabola* (Lu); Kobayashi, p. 389.
1965 *Cyclolorenzella parabola* (Lu); Lu *et al.*, p. 252, pl. 43, figs 1–4.
1965 *Cyclolorenzella rotundata* (Resser & Endo in Endo & Resser); Lu *et al.* (*pars*), p. 253, pl. 43, figs 5, 7 (*non* fig. 6).

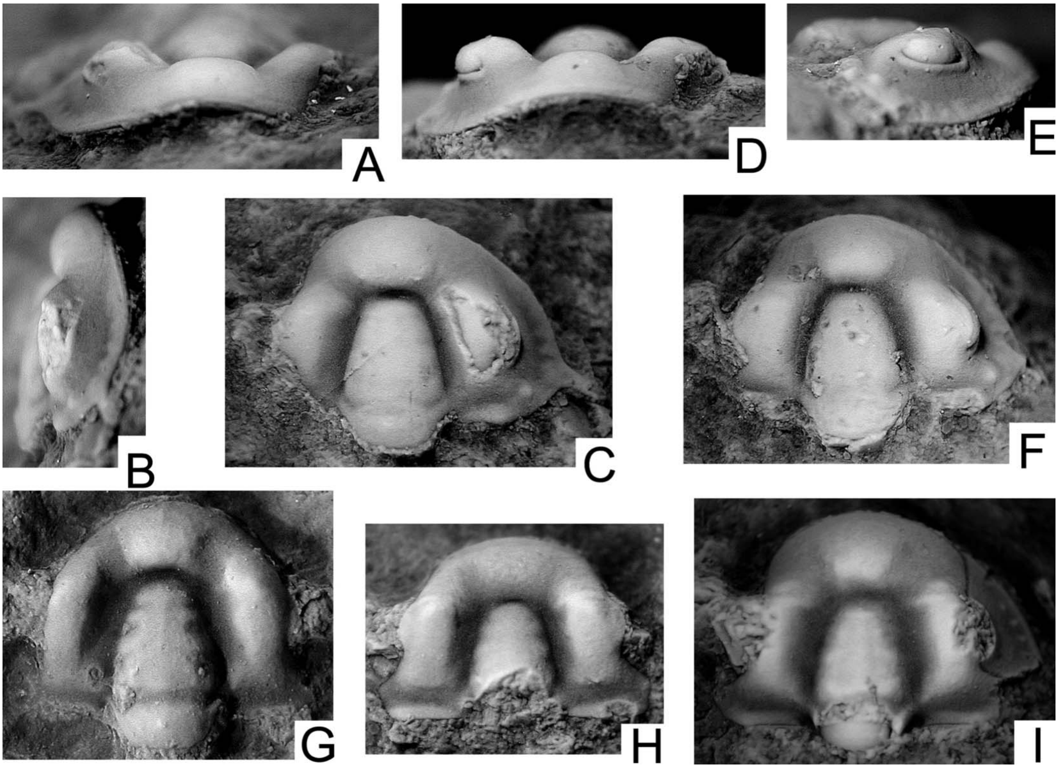


Fig. 6. *Jiulongshania rotundata* (Resser & Endo in Endo & Resser, 1937). All from the interval between 34 m and 43 m above the base of the Kushan Formation, Jiulongshan section, China. **A–C**, anterior, lateral and dorsal views of cranidium with an articulated librigena, SNUP5043, ×10.3. **D–F**, anterior, lateral and dorsal views of cranidium with an articulated librigena, SNUP5044, ×12.1. **G**, internal mould of cranidium, SNUP5050, ×10.7. **H**, small cranidium, SNUP5047, ×13.2. **I**, cranidium with an incomplete librigena, SNUP5048, ×14.4.

1976 *Cyclolorenzella rotundata* (Resser & Endo in Endo & Resser); Nan, p. 336, pl. 196, figs 9–11.

1983 *Cyclolorenzella parabola* (Lu); Qiu *et al*., p. 126, pl. 41, fig. 1.

1987 *Cyclolorenzella acalle* (Walcott); Zhang & Jell (*pars*), p. 132, pl. 51, figs 5–7 (*non* figs 1–4).

1989 *Cyclolorenzella parabola* (Lu); Wittke & Zhu in Zhu & Wittke, p. 213, pl. 5, figs 1–5.

1996 *Cyclolorenzella parabola* (Lu); Guo *et al*., p. 114, pl. 53, figs 1–16.

Lectotpye. One of the cranidia (USNM 86842b, Resser & Endo in Endo & Resser 1937, pl. 46, fig. 5; refigured by Zhang & Jell 1987, pl. 51, fig. 6) is herein selected as the lectotype of the species.

Diagnosis. Cranidium with a convex preglabellar boss defined clearly by a pair of deep, broad and complete divergent furrows on frontal area.

Remarks. Resser & Endo in Endo & Resser (1937) established *Lorenzella rotundata* based on somewhat damaged specimens, but the type material clearly demonstrates a pair of deep and wide furrows on the frontal area that are unique among the species of *Jiulongshania*. *Cyclolorenzella parabola* Lu, 1957 is indistinguishable from, and hence is treated as a junior synonym of, *J. rotundata*.

The most significant morphological feature in the cranidium is the pair of divergent furrows on the frontal area that emerge from the antero-lateral corners of the glabella. The furrows are apparently emphasized by the bulbous preglabellar boss and strongly swollen fixigenae (Fig. 6A, B, D, E). The anterior border is narrow and faintly indicated. Librigenae are significantly different from those of other *Jiulongshania* species in bearing a short genal spine that projects diagonally backward from the postero-lateral corner of the cephalon (Fig. 6C). Chu (1959) and Zhu & Wittke (1989) indicated that the librigenae bear a row of eight nodes along the lateral margin, but the larger specimens on hand (Fig. 6C, I) have only three to five nodes. No pygidia or hypostomes have been found in this study.

Stratigraphic occurrence. Interval between 34 m and 43 m above the base of the Kushan Formation in the Jiulongshan section. Other associated trilobite genera include *Teinistion*, *Monkaspis*, *Bergeronites*, and *Ammagnostus*.

Jiulongshania longispina (Wittke & Zhu in Zhu & Wittke, 1989) (Fig. 7A–Q)

1989 *Cyclolorenzella longispina* Wittke & Zhu in Zhu & Wittke, p. 213, pl. 3, fig. 13.

Diagnosis. Cranidium with weakly convex preglabellar field defined by a pair of weakly divergent short furrows on frontal area; long glabella (greater than one-half of cranidial length); short occipital ring (15–20% of cranidial length); and large palpebral lobes.

Remarks. This species has similarities to *J. acalle* but can be distinguished by the combined morphological features diagnosed above. The PCA result (Fig. 8A) shows that the specimens of *J. longispina* are clustered in the morphospace with negative values on components 1 and 2, whereas those of *J. acalle* occupy a somewhat broad morphospace with generally positive values on components 1 and 2.

Librigenae are sub-triangular in outline, with a long genal spine that projects diagonally backward and is slightly curved (Fig. 7J). The associated pygidia are not significantly different from those of other species, bearing five axial rings (Fig. 7H, I).

Stratigraphic occurrence. Interval between 48 m and 64 m above the base of the Kushan Formation in the Jiulongshan section. Associated genera are *Blackwelderia*, *Teinistion*, *Monkaspis*, *Bergeronites*, *Ammagnostus* and *Kormagnostus*.

Jiulongshania regularis (Walcott, 1906) (Fig. 9A–H)

1906 *Agraulos regularis* Walcott, p. 578.
1913 *Inouyia*? *regularis* (Walcott); Walcott, p. 154, pl. 14, fig. 18.
1959 *Lorenzella pustulosa* Chu, p. 98, pl. 2, figs 6–8.
1960 *Cyclolorenzella pustulosa* (Chu); Kobayashi, p. 389.
1960 *Latilorenzella regularis* (Walcott); Kobayashi, p. 390.
1965 *Cyclolorenzella pustulosa* (Chu); Lu *et al*., p. 253, pl. 42, figs 23–24.
1965 *Cyclolorenzella regularis* (Walcott); Lu *et al*., p. 253, pl. 42, figs 25–26.
1987 *Cyclolorenzella regularis* (Walcott); Zhang & Jell, p. 133, pl. 51, figs 8–9.
1995 *Cyclolorenzella yentaiensis* (Chu); Zhang *et al*., p. 78, pl. 34, figs 12–14.
1996 *Cyclolorenzella regularis* (Walcott); Guo *et al*., p. 115, pl. 59, figs 17–18.

Diagnosis. Cranidium *ca* 1.1–1.3 times wider than long; palpebral lobes located at level corresponding to anterior half of glabella; short occipital ring with a large median node; eye ridges nearly transverse; narrow librigenae without genal spines; and surface ornamented with more-or-less evenly spaced granules.

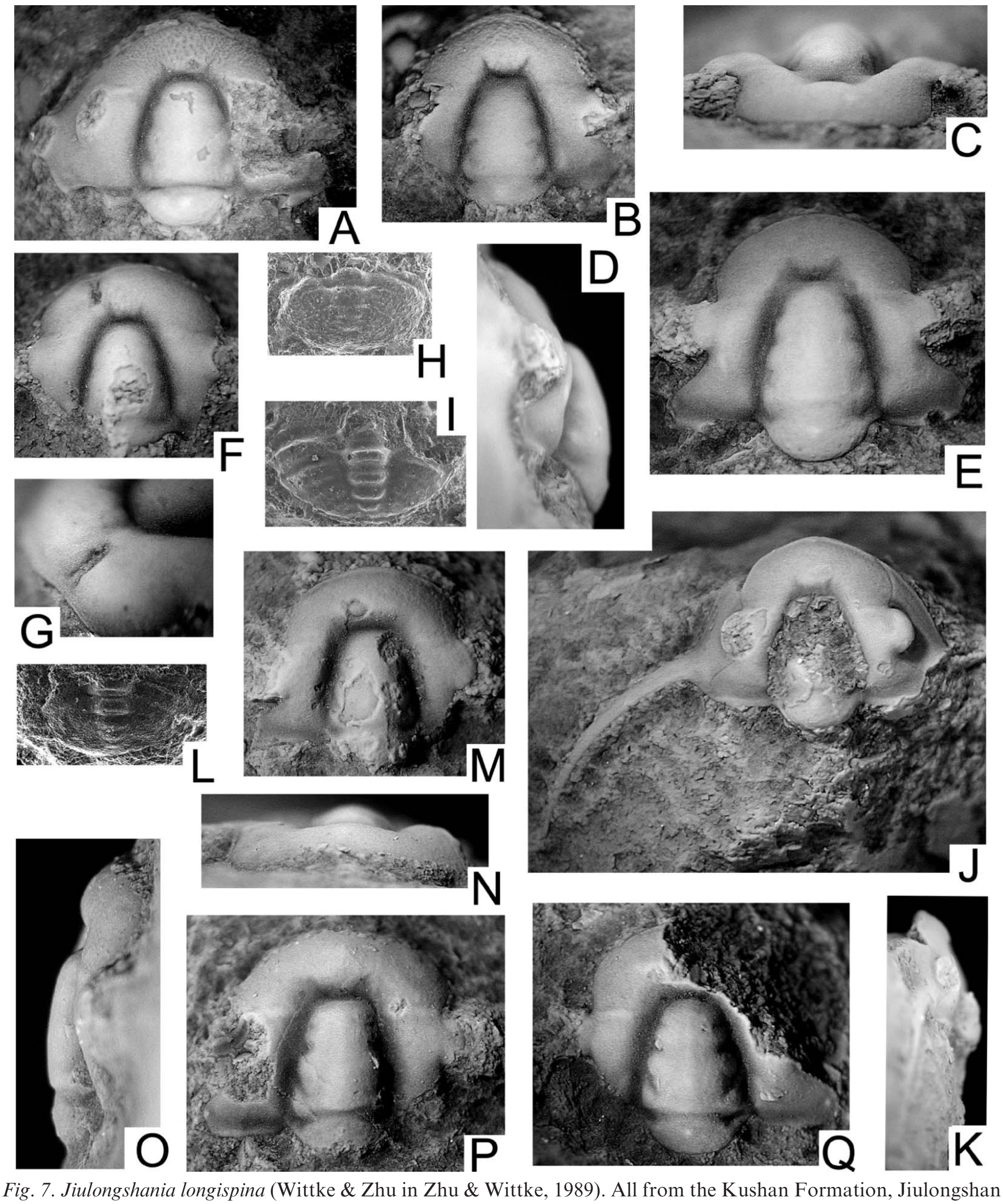


Fig. 7. Jiulongshania longispina (Wittke & Zhu in Zhu & Wittke, 1989). All from the Kushan Formation, Jiulongshan section, China. **A**, cranidium from about 60 m above the base of the Kushan Formation, SNUP5061, ×14.3. **B–K**, cranidia and pygidia from the interval between 54 m and 58 m above the base of the Kushan Formation. **B**, cranidium, SNUP5058, ×13.7. **C–E**, anterior, lateral and dorsal views of complete cranidium, SNUP5059, ×13. **F–G**, cranidium bearing healed injuries, SNUP5066. **F**, dorsal view, ×13.4. **G**, oblique antero-lateral view of the healed injury, ×31.1. **H**, small pygidium, SNUP5067, ×38. **I**, pygidium, SNUP5068, ×33.2. **J–K**, dorsal and lateral views of cranidium articulated with a nearly complete librigena, SNUP5062, ×10.6, ×7.4. **L–Q**, cranidia and pygidium from the interval between 48 m and 51 m above the base of the Kushan Formation. **L**, pygidium, SNUP5069, ×33.9. **M**, cranidium, SNUP5053, ×12.5. **N–P**, anterior, lateral and dorsal views of cranidium, SNUP5052, ×10, ×12.8, ×10. **Q**, incomplete cranidium, SNUP5054, ×10.3.

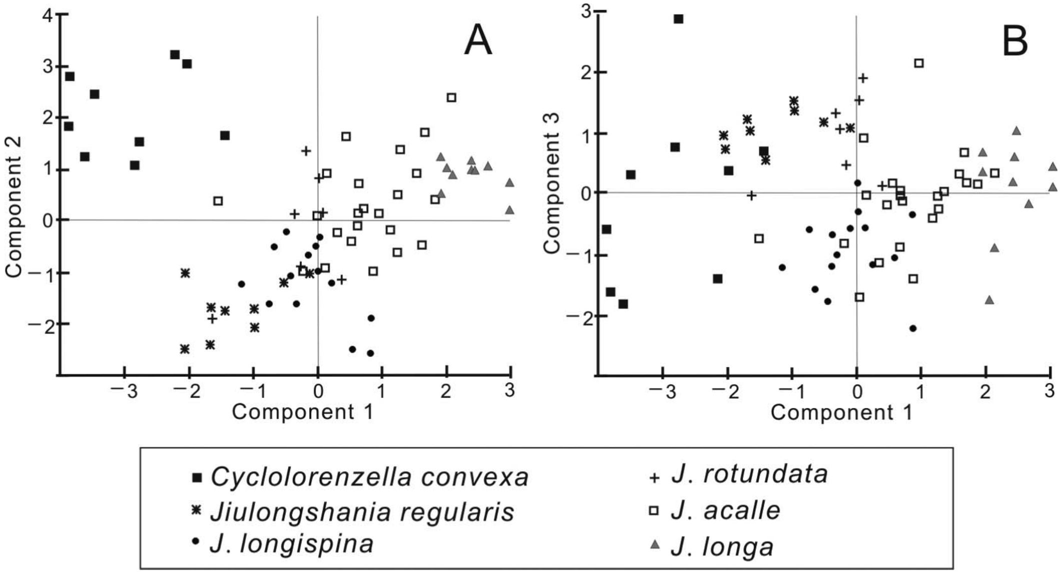


Fig. 8. Scatter plots of the first three principal components for 73 cranidia assigned to *Cyclolorenzella convexa* and five species of *Jiulongshania* after the taxonomic revision has been made. **A**, principal component 1 vs principal component 2. **B**, principal component 1 vs principal component 3.

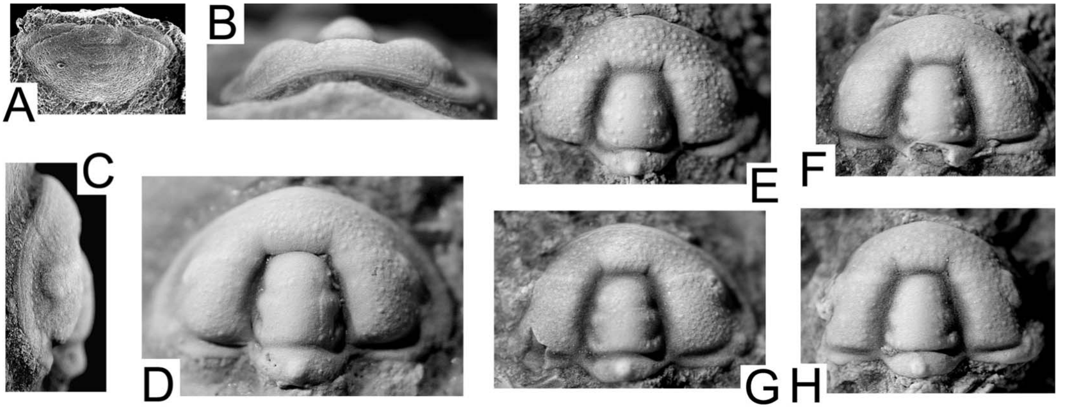


Fig. 9. *Jiulongshania regularis* (Walcott, 1906). All from the Kushan Formation, Jiulongshan section, China, recovered from the interval from 75 m to 82 m above the base of the formation. **A**, small pygidium, SNUP5079, × 32.9. **B–D**, anterior, lateral and dorsal views of cranidium, SNUP5071, × 13.8. **E**, cranidium, SNUP5074, × 12.5. **F**, cranidium, SNUP5072, × 12.5. **G**, cranidium, SNUP5073, × 11.9. **H**, cranidium, SNUP5070, × 11.9.

Remarks. This species is easily distinguished from other *Jiulongshania* species in having a transverse cranidium, librigenae lacking genal spines, nearly transverse eye ridges, and a granulate prosopon. The PCA result (Fig. 8) also demonstrates that *J. regularis* represents an end-member of *Jiulongshania* in occupying the morphospace with negative values on components 1 and 2. Other morphological features include less swollen preglabellar boss (Fig. 9B, C), less conical glabella (Fig. 9D–H), and forwardly convergent anterior branches of the facial sutures.

A small pygidium (Fig. 9A), about 0.35 mm long and 0.63 mm wide, is tentatively assigned to this species. It is subtriangular with four axial rings but the axial furrows are almost invisible.

Stratigraphic occurrence. Interval between 75 m and 82 m above the base of the Kushan Formation in the Jiulongshan section. Associated trilobite genera are *Liostracina*, *Stephanocare*, *Bergeronites*, *Teinistion* and *Kormagnostus*.

Jiulongshania longa sp. nov. (Fig. 10A–K)

Type material. Holotype, SNUP 5010 (Fig. 10I–K); paratypes, SNUP 5003–5009, 5011–5014; lowermost Kushan Formation, Jiulongshan section, Shandong Province, China; middle Cambrian.

Etymology. Referring to the comparatively long cranidia and frontal area.

Diagnosis. Cranidium longer than wide; frontal area long (35–40% of cranidial length); palpebral lobes small (*ca* 20% of cranidial length); a pair of diverging furrows on frontal area insignificantly impressed.

Description. Cranidium semi-circular, as long as wide; surface generally smooth. Glabella twice as long as wide, slightly tapering forward; glabellar front rounded to weakly truncated; lateral glabellar furrow not visible. Occipital ring semicircular, projecting rearward with rounded posterior margin, bearing a small median node and terrace lines subparallel-to-margin in the posterior part (Fig. 10C, F, H, K); occipital furrow wide and shallow; a pair of faint bacula visible in small cranidia (Fig. 10A, B, E). Frontal area moderately convex, greater than 35% of cranidial length; anterior border absent; anterior margin rounded to very weakly angulate; a pair of diverging furrows on frontal area weakly impressed. Papebral lobes small, about 20% of cranidial length, located slightly anterior to glabellar mid-length; eye-ridges indistinct, running obliquely backwards; palpebral area as broad as glabella. Posterior field weakly downsloping abaxially (Fig. 10I); posterior border narrow, defined by wide and moderately shallow posterior border furrow; in the largest specimen, posterior border furrow widening abaxially (Fig. 10H). Anterior branches of facial suture weakly divergent forwards; posterior branches of facial suture divergent backwards; genal angle rounded to slightly angular.

Librigena narrow, crescentic (Fig. 10D); librigenal field narrow; lateral border absent; librigenal spine projecting rearward, very weakly curved adaxially, as long as genal cranidial length; eye socle weakly elevated; distal portion of genal spine ornamented with closely spaced terrace ridges running subparallel to the margin.

Pygidium semielliptical, weakly convex, length about one-half of maximum width. Axis moderately tapering rearward, nearly reaching to posterior margin, with three or four axial rings; ring furrows shallow. Pleural field downsloping marginally; pleural furrow shallow; border not defined.

Remarks. *Jiulongshania longa* is similar to *J. acalle* (Walcott, 1905) and *J. acuta* (Duan in Duan *et al*., 2005) in overall cranidial morphology. *Jiulongshania acalle* has a shorter frontal area (30–35% of cranidial length), less divergent posterior branches of facial sutures, and more anteriorly located palpebral lobes than *J. longa*. *Jiulongshania acuta*, erected on a nearly complete carapace, has a more forward-tapering glabella and more posteriorly situated palpebral lobes than *J. longa*, and was reported to occur in the much older Hsuchuang Formation (mid-middle Cambrian) of Jilin Province (Duan *et al*. 2005).

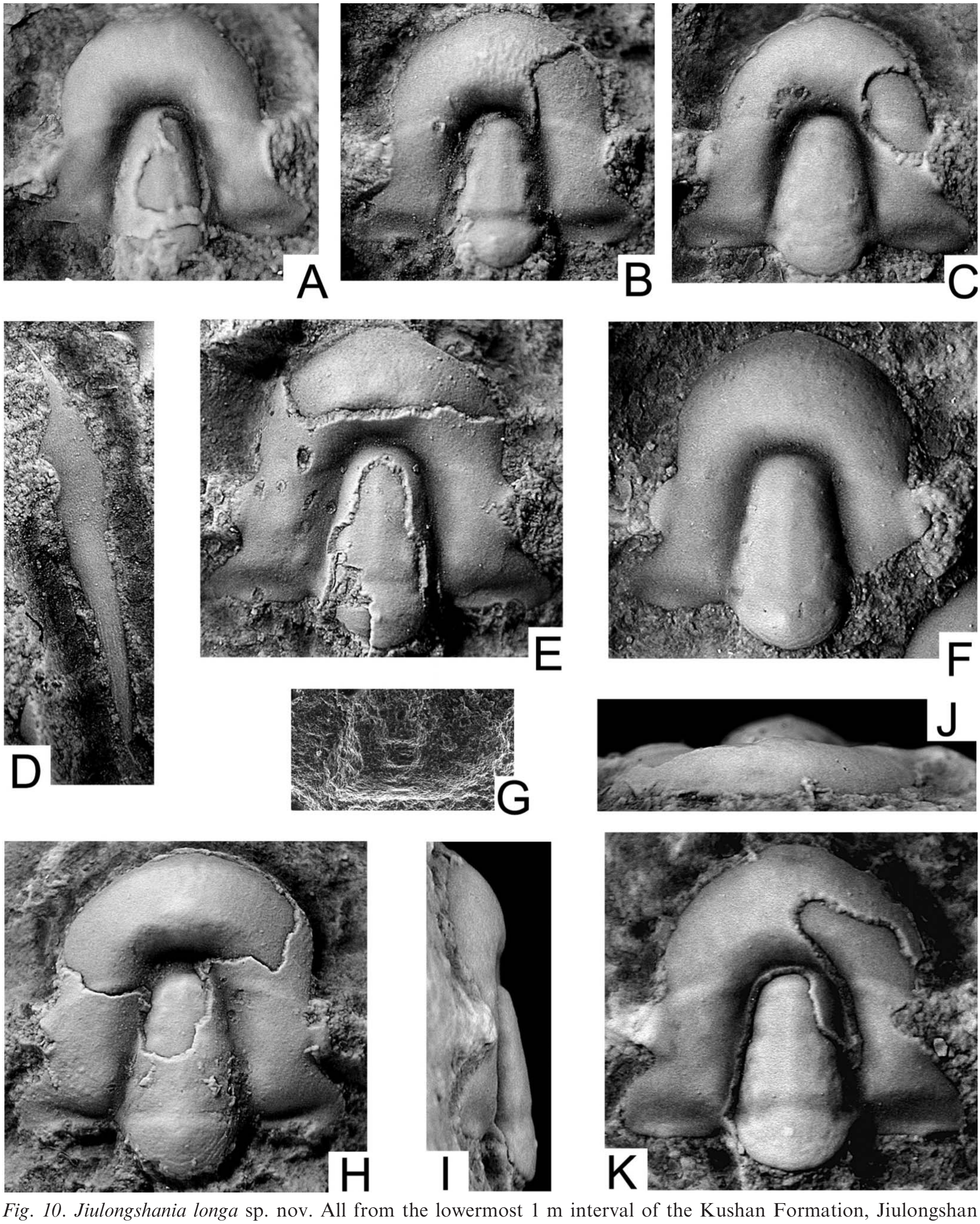


Fig. 10. Jiulongshania longa sp. nov. All from the lowermost 1 m interval of the Kushan Formation, Jiulongshan section, China. **A**, cranidium, SNUP5003, ×17.1. **B**, cranidium, SNUP5004, ×17.1. **C**, cranidium, SNUP5005, ×15.4. **D**, librigena, SNUP5013, ×15.6. **E**, cranidium, SNUP5006, ×14. **F**, cranidium, SNUP5008, ×14. **G**, small pygidium, SNUP5014, ×42.3. **H**, cranidium, SNUP5009, ×9.3. **I–K**, lateral, anterior and dorsal views of holotype cranidium, SNU5010, ×13.3.

Stratigraphic occurrence. Lowermost part (*ca* basal 1 m) of the Kushan Formation in the Jiulongshan section. Associated trilobite genera are *Damesella*, *Teinistion*, *Monkaspis*, and *Ammagnostus*.

Implications for stratigraphic correlation

This study documents the successive occurrences of five species of *Jiulongshania* from the *Blackwelderia* Zone of the Kushan Formation in the Jiulongshan section, Shandong Province, China: they are in ascending order *J. longa*, *J. acalle*, *J. rotundata*, *J. longispina*, and *J. regularis*. *Cyclolorenzella convexa* was recovered from the stratigraphically younger *Drepanura* Zone of the Kushan Formation in the Jiulongshan section, China and of the Sesong Formation in the Jikdong section, Korea.

Previously, stratigraphic information on *Jiulongshania* and *Cyclolorenzella* in China was poorly resolved. Most early studies simply stated the occurrence of *Jiulongshania* or *Cyclolorenzella* in the Kushan Formation (Walcott 1913, Endo & Resser 1937, Lu 1957). Chu (1959) was the first to provide somewhat detailed stratigraphic information for the species of *Jiulongshania* and *Cyclolorenzella* within the Kushan Formation of Liaoning, Shandong, and Jiangsu provinces, namely *J. acalle* (as *Lorenzella kushanensis*), *J.*? *subcylindrica*, *J.*? *yentaiensis*, and *J. rotundata* (as *Lorenzella parabola*) from the *Blackwelderia paronai* Zone and *J. regularis* (as *Lorenzella pustulosa*) and *Cyclolorenzella convexa* from the *Drepanura premesnili* Zone. Zhu & Wittke (1989) documented three species of *Jiulongshania* in the Kushan Formation of Tangshan, Hebei Province: *J. acalle* (as *Cyclolorenzella hebeiensis* and *C. uniforma*) and *J. rotundata* (as *C. parabola*) from the lower part of the formation, and *J. longispina* from the middle part of the formation. Hence, these stratigraphic occurrences of *Jiulongshania* and *Cyclolorenzella* are more-or-less consistent with the present results. On the other hand, a recent report from Liaoning Province by Guo *et al.* (1996) cited somewhat different stratigraphic occurrences of *Jiulongshania* and *Cyclolorenzella*. They recorded *J. acalle* and *J. regularis* from the *Damesella–Yabeia* Zone of the Changhia Formation, *J. rotundata* (as *C. parabola*) from the *Blackwelderia–Damesops* Zone of the Kushan Formation, and *C. convexa* from the *Drepanura–Diceratocephalus* Zone of the Kushan Formation, respectively.

In summary, *Jiulongshania* has a relatively long stratigraphic distribution ranging from the *Damesella–Yabeia* Zone of the Changhia Formation to the *Blackwelderia* Zone of the Kushan Formation, whereas *Cyclolorenzella* is confined to a narrow stratigraphic interval within the *Drepanura* Zone of the Kushan Formation, China, and of the Sesong Formation, Korea.

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Specimen no.	Species assigned	A1	F1	B	E	C	D5	D8	J1	J	K2	K5
SNUP4501	*C. convexa*	1.67	0.40	0.84	0.43	0.42	0.35	0.69	2.08	2.12	0.74	0.37
SNUP4502	*C. convexa*	2.28	0.52	1.21	0.56	0.55	0.54	0.85	2.64	2.69	0.90	0.44
SNUP4503	*C. convexa*	2.46	0.47	1.38	0.61	0.71	0.62	0.87	3.31	3.31	1.21	0.67
SNUP4504	*C. convexa*	2.44	0.60	1.26	0.58	0.55	0.49	1.01	3.53	3.62	1.41	0.74
SNUP4505	*C. convexa*	1.12	0.25	0.55	0.32	0.30	0.30	0.39	1.54	1.53	0.49	0.27
SNUP4506	*C. convexa*	1.38	0.27	0.75	0.36	0.41	0.36	0.47	1.79	1.80	0.56	0.34
SNUP4507	*C. convexa*	1.19	0.24	0.67	0.28	0.29	0.39	0.39	1.69	1.56	0.52	0.30
SNUP5001	*C. convexa*	2.88	0.78	1.47	0.63	0.64	0.69	1.24	3.99	3.74	1.37	0.71
SNUP5002	*C. convexa*	2.38	0.27	0.75	0.36	0.41	0.36	0.47	1.79	1.80	0.56	0.34
SNUP5003	*J. longa*	2.15	0.78	0.94	0.43	0.37	0.44	1.07	2.46	2.07	0.83	0.43
SNUP5004	*J. longa*	2.16	0.83	0.91	0.42	0.40	0.50	1.05	2.56	2.14	0.79	0.49
SNUP5005	*J. longa*	2.40	0.92	1.09	0.41	0.50	0.56	1.13	2.81	2.40	0.95	0.58
SNUP5006	*J. longa*	3.30	1.20	1.44	0.66	0.67	0.65	1.58	3.74	3.04	1.22	0.65
SNUP5007	*J. longa*	3.32	1.26	1.37	0.72	0.72	0.64	1.58	3.49	3.05	1.27	0.70
SNUP5008	*J. longa*	3.27	1.26	1.42	0.59	0.63	0.69	1.53	3.49	2.87	1.24	0.68
SNUP5009	*J. longa*	5.05	1.81	2.18	1.06	0.91	0.11	2.39	5.40	4.67	1.86	1.02
SNUP5010	*J. longa*	3.51	1.30	1.50	0.71	0.66	0.83	1.66	3.91	3.48	1.30	0.78
SNUP5011	*J. longa*	3.21	1.16	1.55	0.51	0.71	0.79	1.50	3.78	3.02	1.15	0.57
SNUP5012	*J. longa*	2.26	0.82	1.01	0.43	0.40	0.59	1.02	2.75	2.19	0.83	0.36
SNUP5015	*J. acalle*	3.76	1.24	1.65	0.86	0.68	0.92	1.58	4.22	3.53	1.65	0.74
SNUP5016	*J. acalle*	2.12	0.65	0.90	0.57	0.45	0.62	0.77	2.54	2.13	0.92	0.50
SNUP5017	*J. acalle*	3.43	1.18	1.40	0.85	0.77	0.74	1.45	3.91	3.50	1.47	0.86
SNUP5018	*J. acalle*	3.48	1.15	0.16	0.71	0.68	0.94	1.41	4.03	3.53	1.41	0.81
SNUP5019	*J. acalle*	3.82	1.19	1.84	0.79	0.82	0.91	1.54	4.38	4.04	1.60	0.90
SNUP5020	*J. acalle*	2.72	0.83	1.24	0.65	0.61	0.62	1.14	2.84	2.67	1.05	0.58
SNUP5021	*J. acalle*	2.42	0.85	1.01	0.56	0.46	0.64	0.99	2.28	2.18	0.84	0.45
SNUP5022	*J. acalle*	3.31	1.05	1.47	0.80	0.63	0.91	1.30	3.55	3.00	1.31	0.66
SNUP5023	*J. acalle*	3.64	1.23	1.62	0.79	0.68	0.87	1.60	3.75	3.30	1.46	0.72
SNUP5024	*J. acalle*	3.65	1.29	1.59	0.77	0.70	0.85	1.64	3.46	3.34	1.36	0.63
SNUP5025	*J. acalle*	3.56	1.17	1.66	0.73	0.73	1.01	1.44	3.91	3.49	1.56	0.68
SNUP5026	*J. acalle*	2.72	0.98	1.21	0.54	0.56	0.72	1.10	2.77	2.53	1.05	0.52
SNUP5027	*J. acalle*	2.56	0.93	1.10	0.52	0.53	0.48	1.25	2.74	2.48	0.94	0.44
SNUP5028	*J. acalle*	3.37	1.23	1.52	0.61	0.66	0.81	1.46	3.34	3.16	1.36	0.59
SNUP5029	*J. acalle*	2.16	0.65	0.99	0.53	0.44	0.60	0.85	2.45	2.10	0.95	0.43
SNUP5030	*J. acalle*	3.78	1.15	1.88	0.75	0.72	0.98	1.57	4.13	3.71	1.56	0.77
SNUP5031	*J. acalle*	2.58	0.76	1.23	0.58	0.46	0.78	0.95	3.00	2.38	1.05	0.53
SNUP5032	*J. acalle*	2.67	0.84	1.19	0.63	0.53	0.68	1.04	3.00	2.44	1.11	0.54
SNUP5033	*J. acalle*	3.10	0.94	1.50	0.66	0.64	0.99	1.07	3.72	3.13	1.34	0.69
SNUP5034	*J. acalle*	3.94	1.30	1.80	0.84	0.85	1.07	1.57	4.26	3.80	1.66	0.72
SNUP5035	*J. acalle*	2.14	0.64	1.03	0.48	0.49	0.60	0.82	2.53	2.07	0.91	0.37
SNUP5036	*J. acalle*	3.12	0.78	1.62	0.72	0.70	0.90	1.09	3.76	3.45	1.48	0.60
SNUP5037	*J. acalle*	3.42	0.98	1.75	0.70	0.72	0.99	1.31	3.96	3.38	1.40	0.72
SNUP5043	*J. rotundata*	3.00	1.01	1.41	0.58	0.80	0.74	1.10	3.52	2.96	1.35	0.76
SNUP5044	*J. rotundata*	2.50	0.84	1.11	0.55	0.65	0.66	0.88	3.08	2.65	1.15	0.57
SNUP5045	*J. rotundata*	2.05	0.68	0.98	0.39	0.55	0.44	0.88	2.44	2.30	0.88	0.50
SNUP5046	*J. rotundata*	2.87	0.96	1.33	0.57	0.71	0.72	1.16	3.53	3.27	1.32	0.77
SNUP5047	*J. rotundata*	2.02	0.59	0.97	0.47	0.52	0.67	0.59	2.68	2.24	0.94	0.59
SNUP5048	*J. rotundata*	2.22	0.80	0.94	0.48	0.56	0.55	0.90	2.72	2.47	0.96	0.57

Appendix 1. Measurements of 11 linear dimensions for 73 cranidia. See Fig. 2 for abbreviations for linear dimensions. All measurements are in millimetres.

(*continued*)

Appendix 1. (*Continued*).

Specimen no.	Species assigned	A1	F1	B	E	C	D5	D8	J1	J	K2	K5
SNUP5049	*J. rotundata*	3.42	1.23	1.49	0.70	0.75	0.85	1.33	3.95	3.79	1.45	0.78
SNUP5051	*J. longispina*	2.42	0.70	1.24	0.48	0.74	0.64	0.87	2.95	2.45	1.05	0.57
SNUP5052	*J. longispina*	3.08	0.92	1.57	0.58	0.73	0.96	1.19	3.92	3.29	1.42	0.81
SNUP5053	*J. longispina*	2.30	0.71	1.16	0.44	0.63	0.59	0.95	3.00	2.45	1.08	0.64
SNUP5054	*J. longispina*	3.22	1.12	1.56	0.54	0.75	1.03	1.24	4.01	3.13	1.51	0.80
SNUP5055	*J. longispina*	1.99	0.60	1.01	0.37	0.51	0.62	0.71	2.55	2.13	0.95	0.52
SNUP5056	*J. longispina*	2.15	0.67	1.05	0.43	0.54	0.53	0.84	2.52	2.22	0.99	0.55
SNUP5057	*J. longispina*	2.19	0.62	1.13	0.44	0.50	0.61	0.83	2.78	2.11	1.06	0.60
SNUP5058	*J. longispina*	2.04	0.67	1.05	0.32	0.44	0.61	0.82	2.40	2.15	0.94	0.42
SNUP5059	*J. longispina*	2.73	0.72	1.38	0.63	0.55	0.87	0.94	3.31	2.70	1.29	0.58
SNUP5060	*J. longispina*	2.04	0.61	1.08	0.35	0.52	0.58	0.72	2.27	2.02	0.88	0.42
SNUP5061	*J. longispina*	2.20	0.62	1.14	0.43	0.50	0.78	0.71	2.52	2.24	1.02	0.45
SNUP5062	*J. longispina*	2.62	0.80	1.30	0.51	0.62	0.79	1.00	2.89	2.58	1.21	0.52
SNUP5063	*J. longispina*	2.48	0.72	1.25	0.51	0.57	0.69	0.95	3.39	2.56	1.13	0.54
SNUP5064	*J. longispina*	2.00	0.61	1.02	0.37	0.48	0.57	0.73	2.59	1.87	0.86	0.43
SNUP5065	*J. longispina*	2.73	0.79	1.34	0.60	0.59	0.89	0.92	3.31	2.73	1.18	0.60
SNUP5070	*J. regularis*	1.79	0.58	0.88	0.33	0.40	0.64	0.60	2.44	2.13	0.88	0.48
SNUP5071	*J. regularis*	1.98	0.63	0.93	0.41	0.37	0.69	0.67	2.71	2.33	1.00	0.56
SNUP5072	*J. regularis*	1.63	0.52	0.81	0.29	0.40	0.52	0.52	2.42	2.03	0.87	0.54
SNUP5073	*J. regularis*	1.78	0.56	0.86	0.36	0.38	0.70	0.56	2.68	2.25	0.91	0.53
SNUP5074	*J. regularis*	1.73	0.60	0.82	0.30	0.34	0.58	0.60	2.35	2.09	0.87	0.49
SNUP5075	*J. regularis*	1.93	0.71	0.91	0.31	0.43	0.57	0.73	2.49	2.20	0.90	0.52
SNUP5076	*J. regularis*	2.02	0.73	0.96	0.32	0.47	0.61	0.73	2.66	2.37	0.95	0.61
SNUP5077	*J. regularis*	1.95	0.64	0.99	0.32	0.46	0.66	0.65	2.79	2.53	0.97	0.57
SNUP5078	*J. regularis*	1.63	0.53	0.81	0.29	0.33	0.59	0.57	2.44	2.10	0.82	0.50