Late Ordovician trilobites from the Xiazhen Formation in Zhuzhai, Jiangxi Province, China

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Trilobites from mudstone of the Upper Ordovician Xiazhen Formation of South China are described. The reef-associated, unique fauna comprises 25 species, 14 genera, and ten families. Five new species are named: *Remopleurides xiazhenensis* sp. nov., *Hibbertia aodiensis* sp. nov., *Vietnamia yushanensis* sp. nov., *Ceraurinus zhuzhaiensis* sp. nov., and *Pliomerina tashanensis* sp. nov. The paucity of trilobites in reef-associated carbonates is interpreted that the trilobites diversified after the reef system decimated. Compared to the Late Ordovician trilobite faunas in other areas of South China, the Xiazhen mudstone fauna is unique in that the phacopids including *Vietnamia*, *Ceraurinus*, and *Pliomerina* account for 75% of the specimens collected. The occurrence of the same trilobite assemblage at different sampling localities along the dip direction of the formation suggests that the outcrops may be overlapped due to structural movement. The Xiazhen trilobite fauna is unique among the Late Ordovician fauna in that it is predominated by phacopids and associated with reef.

Key words: Trilobita, Ordovician, Xiazhen Formation, Zhuzhai, Jiangxi Province, China.

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Introduction

The Upper Ordovician Xiazhen Formation in South China is well known for its reefs, mainly consisting of tabulate corals, stromatoporoids, and algae (Li et al. 2004; Zhang et al. 2007). The formation is also known to yield diverse other invertebrate fossils including brachiopods, cephalopods, gastropods, and trilobites. The brachiopod fauna has been well studied with focus on biostratigraphy and palaeobiogeography (e.g., Zhan and Cocks 1998; Zhan et al. 2002). In contrast, other invertebrates have received little attention and only their stratigraphical occurrences have been recorded. In the case of trilobites, the identification has been made at most to the genus level (see Chen et al. 1987; Zhang et al. 2007) and a proper systematic treatment has not been completed. Many trilobite specimens including several well-preserved articulated carapaces were collected from the mudstone rocks of the formation. This study systematically describes and illustrates this trilobite fauna.

Institutional abbreviations.—NIGP, Nanjing Institute of Geology and Palaeontology, Nanjing, China.

Other abbreviations.—exsag., exsagittally; L, glabellar lobe; S, glabellar furrow; sag., sagittally; tr., transversally.

Material and methods

The Xiazhen Formation consists of carbonates comprising tabulate coral/stromatoporoid reef and tidal/lagoonal limestone, and siliciclastics of mudstone/shale. The trilobites are known to occur in both mudstone and limestone beds (Chen et al. 1987; Zhang et al. 2007). Trilobite specimens were collected from the mudstone beds at five localities (Fig. 1). The mudstone is yellow brownish to olive greenish in colour, heavily weathered, and fractured at some localities (Fig. 2). The mudstone strata vary from a few decimetres (localities 1, 3, 4, and 5) to a few metres (locality 2) in thickness; it was not possible to accurately measure the thickness due to the deformation and weathering of the strata. Over 200 specimens were collected (Table 1); some are completely articulated. The specimens are mostly internal molds, but some have exoskeleton preserved. The specimens are moderately distorted in various directions. Latex casts were prepared for external molds to observe their external morphology.

Geological setting

The Xiazhen Formation is exposed at Zhuzhai in Yushan County, Jiangxi Province, China (Fig. 1). The formation is as-

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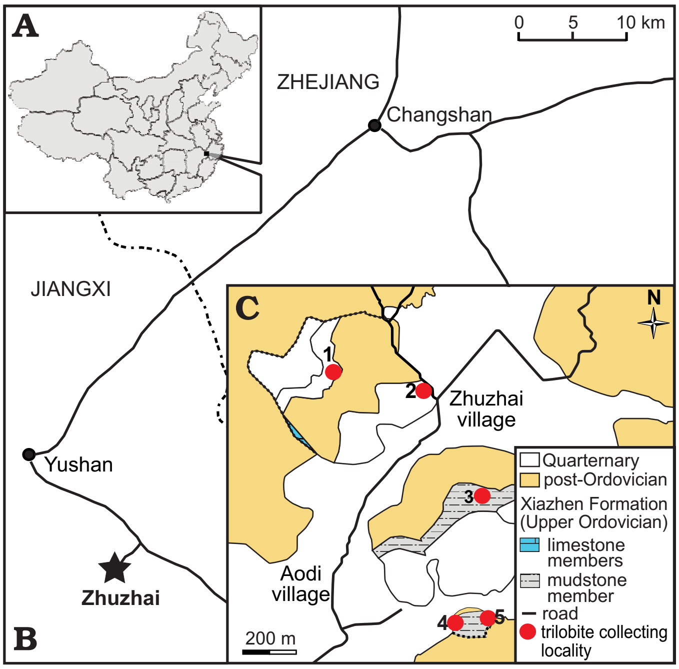

Fig. 1. Location of trilobite collecting localities at Zhuzhai, Jiangxi Province, China. GPS coordinate of the locality 2 is 28°34'23.27" N and 118°20'16.50" E. **A**. The map of China showing the sampling locality (the black rectangle). **B**. The magnified view of the rectangled area in A. **C**. Geologic map of the sampling locality.

signed to *Dicellograptus complexus* Graptolite Zone and is of late Katian (mid-Ashgill) age (Zhang et al. 2007: fig. 2-2); no biostratigraphical zones based on trilobites have been established for the stratigraphical interval in South China represented by the Xiazhen Formation. The formation is considered to be contemporaneous with the Sanqushan and Changwu formations; each formation is interpreted to represent co-existing sedimentary facies (lower-relief reef in shelf interior for the Xiazhen Formation, carbonate mudmound along shelf rim for the Sanqushan Formation, and fine detrital deposits in outer shelf for the Changwu Formation, respectively) in a rimmed shelf setting (Li et al. 2004: fig. 12).

Compared to the abundance and diversity of trilobites in the mudstone, fewer trilobites were found in reef-associated limestone in this study. Previous works have recorded trilobite occurrences in the limestone intervals (Zhang et al. 2007: 86–90); however, the abundance data was not compiled and only the taxon names are listed for each horizon. The occurrences documented in the previous works, but not in this study (units 3, and 13–15; see Table 2) are consistently associated with mudstone or shale lithology (see Zhang et al. 2007); even in these occurrences, only two genera were recorded (Table 2).

Only a few trilobite specimens were collected by this study (e.g., Fig. 6H) from the limestone layers where reef-building organisms are found. Considering abundant occurrence of well-preserved tabulate corals and stromatoporoids, the relative paucity of trilobites in reefal limestone, the paucity might be due to taphonomic control on taxonomic abundance (see Westrop 1986). Alternatively, the paucity suggests that the trilobites from the mudstone did not co-exist

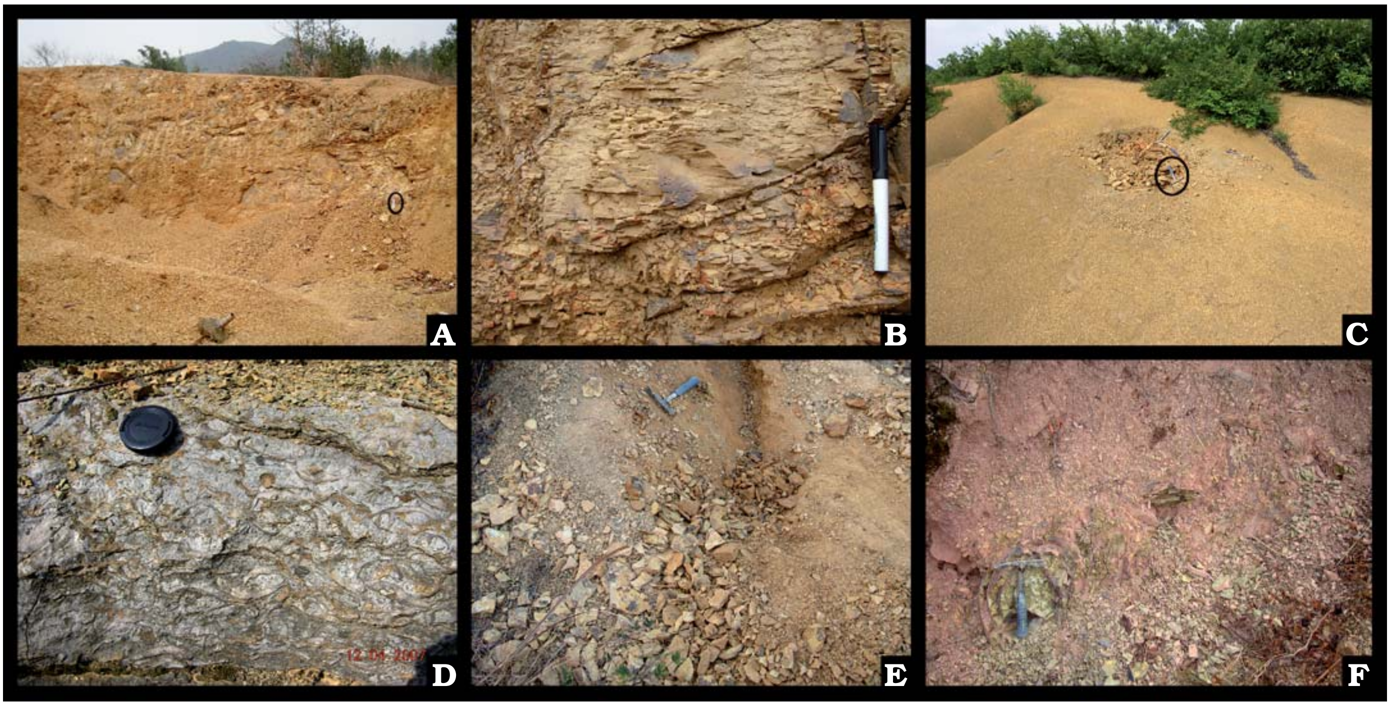

Fig. 2. Outcrop photographs of sampling localities. Hammer in C, E, and F is about 26 cm long. **A**. Mudstone outcrop at locality 2; water bottle in the elipse is about 20 cm high. **B**. Close-up view of mudstone at locality 2; pen is about 13.5 cm long. **C**. Mudstone outcrop at locality 1. **D**. Brachiopod lag deposit supposedly underlying mudstone at locality 1; camera lens cap is about 5 cm in diameter. **E**. Mudstone outcrop at locality 3; a trench was dug to collect specimens. **F**. Mudstone outcrop at locality 4.

Table 1. Occurrence and faunal composition of the trilobite fauna in the mudstones of the Xiazhen Formation.

Order	Family	Faunal type	Species	Number of specimens per sample locality					Total	Proportion of the fauna (%)
				1	2	3	4	5		
Asaphida	Remopleuridae	Ibex I	*Remopleurides xiazhenensis* sp. nov.	2	11		2	3	18	8.8
			Remopleurides aff. *nasutus*		2			2	4	2.0
	Nileidae	Ibex II	*Nileus* sp.		1				1	0.5
	Asaphidae	Ibex II	Asaphidae indet.		1	9			10	4.9
Corynexochida	Styginidae	Whiterock	*Meitanillaenus*? sp.			7			7	3.4
			Eokosovopeltis sp.		1				1	0.5
			Eokosovopeltis cf. *currajongensis**							
			Styginidae indet. sp. A			2			2	1.0
			Styginidae indet. sp. B			2			2	1.0
Harpetida	Harpetidae	Whiterock	*Hibbertia aodiensis* sp. nov.		5				5	2.4
			Scotoharpes sp.				1		1	0.5
Lichida	Lichidae	Whiterock	*Amphilichas* sp.			1			1	0.5
Phacopida	Calymenidae	Whiterock	*Vietnamia yushanensis* sp. nov.	6	39	12	8	4	69	33.7
			Vietnamia sp. A		1				1	0.5
			Vietnamia sp. B				3		3	1.5
			Vietnamia sp. C	1					1	0.5
			Vietnamia sp. D			2	1		3	1.5
			Vietnamia sp. E	1	1			1	3	1.5
			Vietnamia? sp.		1				1	0.5
			cf. *Reedocalymene* sp.					1	1	0.5
			Neseuretinus? sp.			6			6	2.9
	Cheiruridae	Whiterock	*Ceraurinus zhuzhaiensis* sp. nov.		24		5		29	14.1
	Encrinuridae	Whiterock	*Erratencrinurus* aff. *trippi*	10					10	4.9
	Pliomeridae	Ibex II	*Pliomerina tashanensis* sp. nov.			22			22	10.7
			Pliomerina sp.			4			4	2.0
Total				20	87	67	20	11	205	

* This specimen is collected from a limestone layer above the mudstone at Locality 1.

with reef-building organisms. A brachiopod lag deposit (Fig. 2D) underlies the mudstone at locality 1 and 2, although the direct contact was not detected, indicating that the mudstone is likely to have been deposited during a period of rapid relative sea-level rise. It seems that this sea-level rise played a crucial role in decimating the reef system, and the trilobites diversified afterwards.

Systematic palaeontology

The terminology adopted below follows Whittington and Kelly (1997) for most taxa and Ebach and McNamara (2002) for the Harpetidae. Open nomenclature usage follows the recommendation made by Bengtson (1988). Measurement values in percentage are in average.

Class Trilobita Walch, 1771

Order Asaphida Salter, 1864

Family Remopleuridae Hawle and Corda, 1847

Genus *Remopleurides* Portlock, 1843

Type species: *Remopleurides colbii* Portlock, 1843; middle Caradoc of Ireland; by subsequent designation of Miller (1889); re-described and illustrated by Whittington (1950).

Remopleurides xiazhenensis sp. nov.

Figs. 3A, 4, 5A, B, F–K, M.

Etymology: After the Xiazhen Formation where the species occurs.

Holotype: NIGP-151979, an articulated specimen from locality 5.

Type locality: Locality 5, about 800 m south of Zhuzhai, Yushan County. GPS coordinate is 28°33'57.97" N and 118°20'25.87" E.

Type horizon: Xiazhen Formation, Upper Ordovician, *Dicellograptus complexus* Graptolite Zone.

Material.—Four articulated exoskeletons, ten thoraco-pygidia, two thoraces, and two cranidia (repository numbers: NIGP-151978, 151979, 151981–151983, 151985–151990)

Diagnosis.—Species of *Remopleurides* with non-spinose, entire pygidial margin and longitudinal ridges on occipital ring and thoracic axial rings.

Description.—Dorsal exoskeleton elliptical in outline, gently tapers backwards, and moderately convex. Cephalon semi-circular in outline. Axial furrow extremely narrow and deep. Glabella sub-circular in outline with maximum (tr.) width at

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Table 2. Stratigraphical position of the sampling localities with reference to the lithological column by Chen et al. (1987: fig. 1) and Zhang et al. (2007: fig. 4-2).

Stratigraphical unit	Collection number	Brachiopods	Trilobites	Locality in this study
19	Yz'18-89	*Antizygospira liquanensis* *Sowerbyella sinensis*		
18	Yz'18	*Oxoplecia* *Sowerbyella sinensis* *Strophomena* *Antizygospira liquanensis* *Eospirigerina*		locality 4/5
17	Yz'17	*Tcherskidium jiangshanensis* *Antizygospira liquanensis* *Ovalospira dichotoma* *Triplesia zhejiangensis* *Eospirifer praecursor*		
16	covered			
15	Yz'15, Yz37-44	*Tcherskidium jiangshanensis*	*Remopleurides* sp.	
14	Yz'14, Yz35	*Tcherskidium jiangshanensis*	*Remopleurides* sp.	
13	Yz'13, Yz33-34		*Dulanaspis*	
12	Yz'12, Yz32			
11	Yz'11, Yz29-31	*Eospirifer praecursor* *Ovalospira dichotoma* *Plectoglossa* sp.	*Dulanaspis*? *Pliomerina* *Lichas*	locality 3
10	Yz'10, Yz24-28			
9	no collection			
8	no collection			
7	Yz'7, Yz23	*Sowerbyella* *Strophomena* *Antizygospira*	*Cheirurus* *Remopleurides* *Calymenesun* *Dulanaspis* *Eoharpes* *Illaenus* *Eobronteus*	locality 1/2
6	no collection			
5	YZ 4-3', Yz'5, Yz21-20	*Altaethyrella zhejiangensis* *Ovalospira dichotoma* *Sowerbyella sinensis* *Antizygospira liquanensis* *Eospirigerina yulangensis* *Eosotrophina uniplicata*		
4	Yz'4	*Tcherskidium jiangshanensis*		
3	Yz'3, Yz19		*Remopleurides*	
2	YZ3(1-3), Yz'2, Yz18	*Eospirifer praecursor* *Antizypospira liquanensis* *Plectoglossa* sp.		
1	Yz'1, Yz16	*Tcherskidium jiangshanensis*		
A1	FZ3	*Eospirifer praecursor* *Tcherskidium jiangshanensis*		

mid-palpebral point; postero-most part waisted and defined by axial furrows that are straight and run moderately convergent backwards; most glabellar area nearly flat. Glabellar tongue rapidly bends downwards and gently tapers forwards. Glabellar surface covered with fine, sub-parallel terrace lines arranged in concentric fashion that become indistinct toward center of glabella (more clearly seen in external mold). Occipital ring elongated (tr.) spindle-shaped; lateral profile mushroom-shaped (nearly flat, laterally expanded dorsal part and constricted middle part); base protruded outwards in triangular shape beyond dorsal outline of occipital ring; about 20 longitudinal ridges developed that are slightly curved outwards and become indistinct adaxially. Occipital furrow straight and deep. Palpebral lobe narrow. Preocular and palpebral area of fixigenae absent; postocular area narrow and triangular in outline. Posterior branch of facial suture sinusoidal.

Librigena with moderately long, stout genal spine; librigenal field gently slope downwards and ornamented with moderately raised terrace-ridges. Eye large and crescentic in outline with exsagittal length being 80% of glabellar sagittal length; eye socle narrow and eye socle furrow moderately deep and wide. Posterior librigenal border narrow and disappear distally. Presence of lateral librigenal border and furrow not observed.

Thorax of 11 segments. Axis gently tapers backwards; maximum width (located between second to fourth segment) about 60% of maximum thoracic width. Axial ring strongly convex and lateral profile identical to occipital ring; up to about 20 longitudinal ridges present; number of ridges progressively reduced towards posterior segments. Articulating furrow wide, steep-sided, and deep but become shallow adaxially. Articulating half ring with a pair of elongated pits; each pit located at adaxial one-quarter of axial ring; anterior margin appears to be broadly notched medially, forming dish-shaped outline. Axial spine on the eighth (from the anterior) segment projected posteriorly and narrow-based; exact length not known. Pleura rhomboidal in outline. Pleural furrow arrowhead-shaped in outline, obliquely directed, and separates pleura into two bands of unequal size. Anterior pleural band much larger than posterior one; anterior band convex, gently slopes forwards and steeply backwards; posterior band convex with equal steepness; dorsal surface of anterior band ornamented with fine terrace lines parallel to outer pleural margin, whereas no distinct lines on posterior band. Fulcral process large, strongly raised, moderately curved distally, and located adaxial one-third of pleura; fulcral socket follows outline of fulcral process. Pleural doublure ornamented with fine terrace lines that run parallel to outer pleural margin; crescentic articulating facet present on posterior half of doublure; dorsal surface of articulating facet smooth.

Pygidium small and sub-elliptical in outline. One axial ring present and divided into two strongly convex lobes by sagittal furrow. Fulcral process narrow and elongated. No pleural region present. Pleural border slightly concave. Pygidial margin non-spinose. Pygidial doublure ornamented with fine terrace lines that are parallel to pygidial margin.

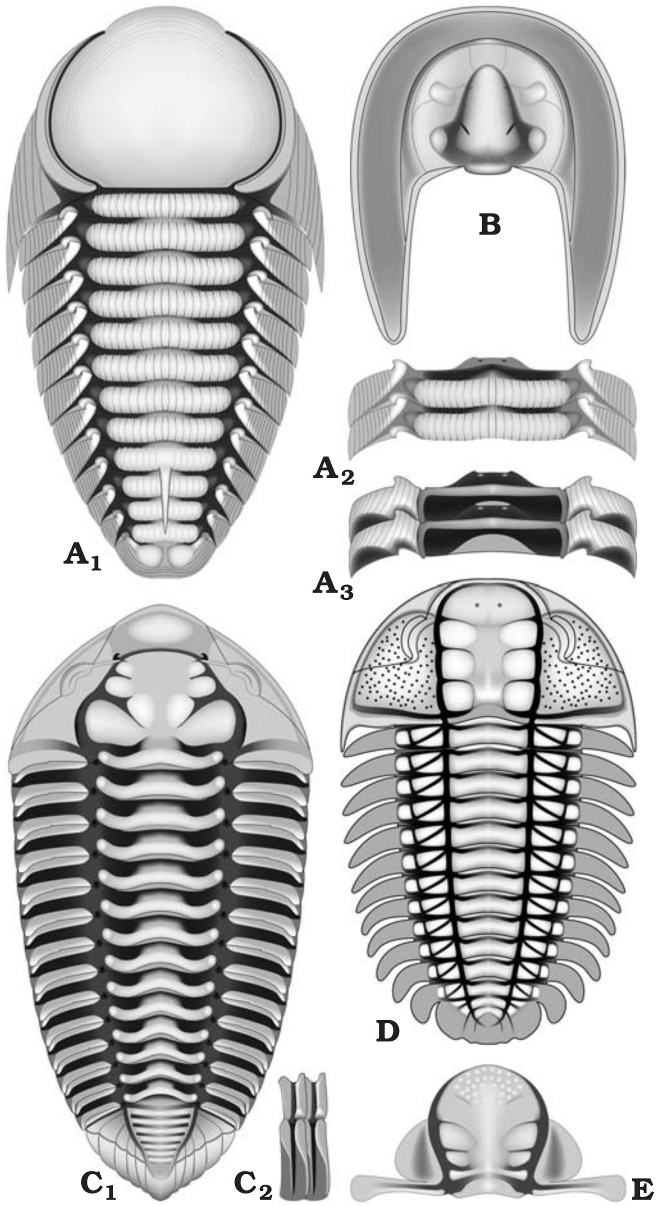

Fig. 3. Reconstruction of new species described from the Late Ordovician Xiazhen Formation; all drawings are not to scale. **A**. *Remopleurides xiazhenensis* sp. nov., dorsal view of exoskeleton (A_1), and dorsal (A_2) and ventral (A_3) view of thoracic segments; exact extent of thoracic axial spine in A_1 is not known and articulating half ring is reconstructed as if the anterior margin is broadly notched (see text for details). **B**. *Hibbertia aodiensis* sp. nov., dorsal view of exoskeleton; pits and caeca are omitted. **C**. *Vietnamia yushanensis* sp. nov., dorsal view of exoskeleton (C_1) and lateral view of thoracic segments (C_2); granules (see Fig. 9N) are omitted. **D**. *Ceraurinus zhuzhaiensis* sp. nov., dorsal view of exoskeleton; granules (see Fig. $10B_1$, B_3) are omitted. **E**. *Pliomerina tashanensis* sp. nov., dorsal view of cranidium.

Remarks.—Morphological features that distinguish *Remopleurides xiazhenensis* sp. nov. from other *Remopleurides* species are: (i) non-spinose, entire pygidial margin (see Figs. $4C_2$, $5B_2$, G), (ii) longitudinal ridges on the occipital ring and thoracic axial rings (see Fig. $4A_1$, C_3), and (iii) a pair of elongated pits on thoracic articulating half ring (see Fig. $4A_1$).

(i) Non-spinose pygidial margin: *Remopleurides xiazhenensis* sp. nov. has an entire pygidial margin (see Fig. $3A_1$), while most *Remopleurides* species have two pairs of blade-shaped spines along pygidial margin; for example, *Remopleurides colbii* Portlock, 1843 (see Whittington 1950: pl. 70: 1), *Remopleurides eximius* Whittington (1959: pl. 15: 7), *Remopleurides pattersoni* Chatterton and Ludvigsen (1976: pl. 1: 49). There are several *Remopleurides* species from China and Kazkhstan for which thoraco-pygidial specimens showing the similar overall morphology to *R. xiazhenensis* are figured: *R. taliangensis* Chang and Fan, 1960 from Qinghai, China; and *R. qilangensis* Zhang, 1981, *R. qiakuertensis* Zhang, 1981 from Xinjiang, China; *R. pisiformis* Weber, 1948, *R. mukatchensis nordicus* Koroleva, 1982, *R. mukatchensis fastigatus* Koroleva, 1982, *R. giganteus* Koroleva, 1965, *R. triplexus* Koroleva, 1982, *R.* cf. *cinghizus* from Kazakhstan.

Of these, the presence of a small pygidium with non-spinose margin is confirmed for *R. mukatchensis fastigatus* Koroleva (1982: pl. 7: 4, 5) and *R.* cf. *cinghizus* (Koroleva 1982: pl. 14: 4a). The pygidia of both species, however, dif-

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fer from those of *Remopleurides xiazhenensis* sp. nov. in having concentric terrace lines (for the first) and straight ridges (for the second species) on the doublure of marginal border; *R. xiazhenensis* has terrace lines that are parallel to the border (Figs. 4C_2, 5B_2). Although the specimens of other species apparently have a small pygidium, they are too poorly preserved to compare their posterior margin in detail.

(ii) Longitudinal ridges on occipital ring and thoracic axial rings: *Remopleurides* species show various ornaments on occipital ring and thoracic axial rings; for example, transverse terrace lines and tubercles are developed in *Remopleurides perspicax* Nikolaisen (1983: see pl. 6: 6, 8) and *R. eximius* Whittington (1959: pl. 15: 7), concentric terrace lines in *R. amphitryonoides* Lu, 1975 (see Zhou et al. 2005: pl. 2: 13, 17) and *R.* cf. *exallos* (Edgecombe and Webby 2007: fig. 12G, H), and tubercles in *R. pattersoni* Chatterton and Ludvigsen (1976: pl. 1: 49). The longitudinal ridges are present in such Kazakhstan *Remopleurides* species as *R. pisiformis* (see Weber 1948: pl. 2: 29a, b; Koroleva 1982: pl. 9: 3a, b), *R. cinghizus* Koroleva (1982: pl. 14: 1, 2), and *R. akdombackensis* Koroleva (1982: pl. 15: 2). In regard to glabellar morphology, *R. pisiformis* (Weber 1948: pl. 2: 27–29; see also Koroleva 1982: pl. 8: 3a, pl. 9: 1) is most similar to *R. xiazhenensis* sp. nov.; *R. cinghizus* differs in having tuberculated glabellar surface (Koroleva 1982: pl. 13: 9) and *R. akdombackensis* in having more elongated (sag.) glabellar tongue (Koroleva 1982: pl. 15: 1). Cranidia of *R. pisiformis* differs in having terrace lines that cover the entire glabellar surface and are arranged in fingerprint-like fashion (terrace lines in *R. xiazhenensis* are strongly developed on anterior and lateral glabellar area and become indistinct toward the glabellar central area; see Fig. 4A_3), and three pairs of glabellar furrows (no glabellar furrows are recognized in *R. xiazhenensis*). It cannot be determined whether or not *R. pisiformis* has a non-spinose, entire pygidial margin from the illustrations. However, Koroleva (1982: 71) mentioned the presence of a notch along pygidial margin as a coaptative device that is well observed in *Remopleurides perspicax* (Nikolaisen 1983: pl. 5: 2, 4), which suggests the presence of a spinose posterior pygidial margin.

The two *Remopleurides* species which have a non-spinose pygidial margin, *R. mukatchensis fastigatus* Koroleva (1982) and *R.* cf. *cinghizus* (Koroleva 1982) have transverse terrace lines (in the first species, see Koroleva 1982: pl. 7: 5) and tubercles (in the second, see Koroleva 1982: pl. 14: 4a).

(iii) A pair of elongated (tr.) pits on articulating half rings: The paired pits are observed where dorsal exoskeleton and doublure of the thoracic axial rings is partially exfoliated (see Fig. 4A_1, C_3). Since the ventral surface of the axial rings is not available, it cannot be determined whether the paired pit has a corresponding protruded structure on the doublure of axial rings. Silicified specimens of *Remopleurides* do not have a comparable ventral projection from the thoracic axial rings (see Whittington 1959: pl. 12: 17, pl. 14: 2; Chatterton and Ludvigsen 1976: pl. 1: 17, 31). The function of this paired pit is yet to be understood.

The ventral surface of the silicified specimens shows that the anterior margin of the articulating half rings is broadly notched posteriorly. In *Remopleurides xiazhenensis* sp. nov., the preserved portion of the doublure of axial rings shows a sharp, dish-shaped posterior margin (see eighth thoracic segment of Fig. 4A_1 and third thoracic segment of Fig. 4C_3), which has a similar outline as in the silicified specimens. The paired pits are located right at the boundary of the posterior margin (see Fig. 4C_3), indicating that the margin may not truly reflect the notched anterior margin of the articulating half ring. However, such sharpness of the posterior margin implies that the anterior margin of the articulating half rings is notched (the exact extent is not known) but post-mortem deformation has slightly displaced the thoracic segments, resulting in the configuration as it is.

Except for the last feature which is only discernible where the specimen is properly exfoliated, none of *Remopleurides* species bear both non-spinose pygidial margin and longitudinal ridges on thoracic axial rings.

Stratigraphic and geographic range.—Late Ordovician and Jiangxi Province, South China.

Remopleurides aff. *nasutus* (Lu, 1957)

Fig. 5C–E, L.

Material.—Three cephalo-thoraces and one cranidium (repository numbers: NIGP-151991–151994).

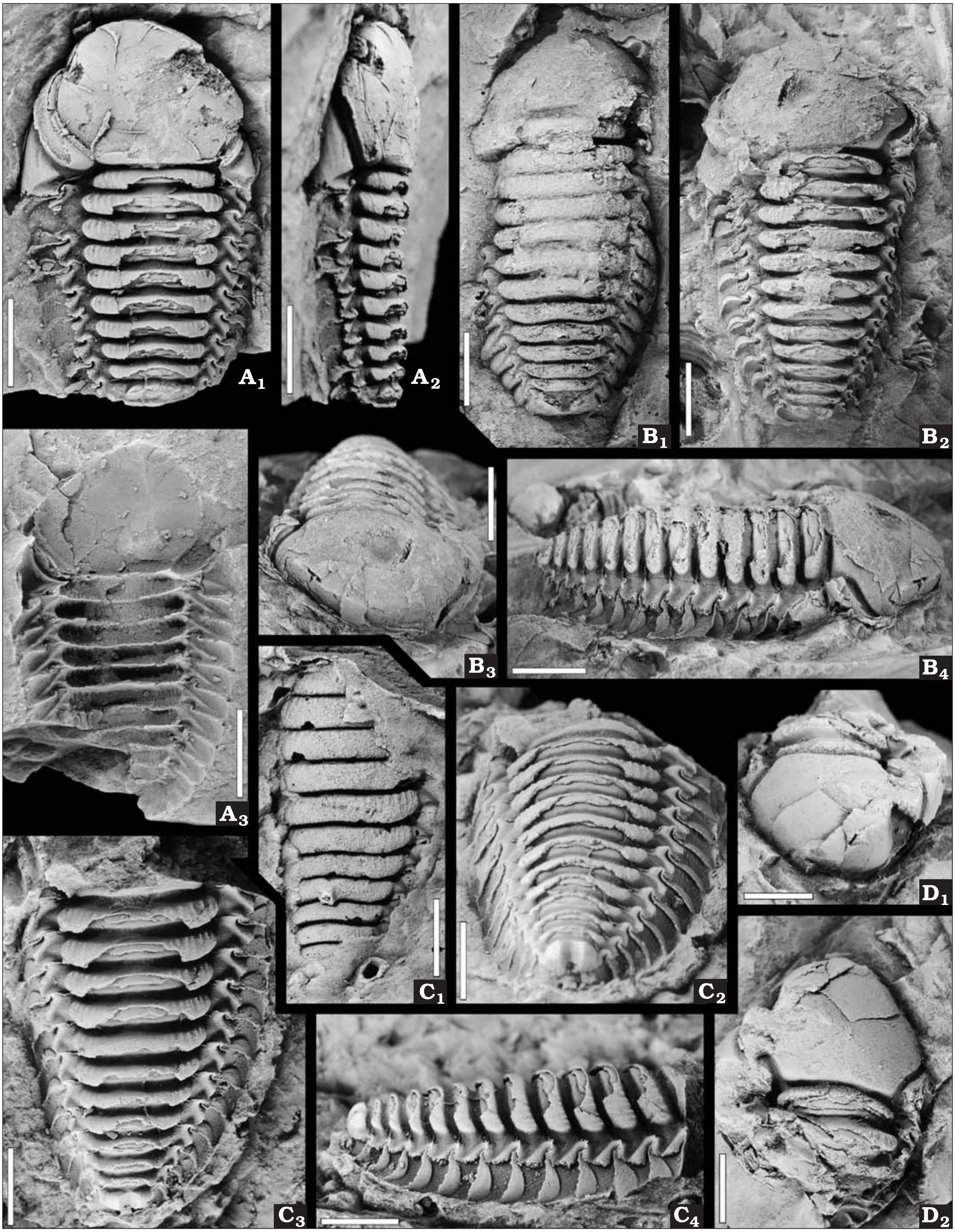
Remarks.—This species is readily distinguished from the coeval *Remopleurides xiazhenensis* sp. nov. by its sub-hexagonal glabella. Due to the poor preservation, the presence of the longitudinal ridges on occipital ring and thoracic axial rings diagnostic of *R. xiazhenensis* cannot be determined. The sub-hexagonal glabella and occipital and thoracic axial ring width are comparable to those of *Remopleurides nasutus* Lu, 1957 (see Lu 1975: pl. 4: 1, 2) from Shaanxi and Hubei, China.

Family Nileidae Angelin, 1854

Genus *Nileus* Dalman,1827

Type species: *Asaphus* (*Nileus*) *armadillo* Dalman, 1827, probably from the Arenig (the Expansus Limestone) of Sweden.

Fig. 4. Asaphid trilobite *Remopleurides xiazhenensis* sp. nov. from the Late Ordovician Xiazhen Formation near Zhuzhai, Yushan County, China. →
A. NIGP-151978, cephalo-thorax with nine thoracic segments from locality 2; dorsal (A_1) and lateral (A_2) views, and ventral view of external mould (A_3); note a pair of elongated pits on articulating half rings, in particular, on the first ring (A_1). **B**. NIGP-151979, holotype, articulated specimen from locality 5; dorsal (B_1) view of cast of external mould, and dorsal (B_2), anterior (B_3), and lateral (B_4) views; note the presence of axial spine on eighth (from the anterior) thoracic segment in B_1. **C**. NIGP-151980, thoraco-pygidium from locality 2; dorsal view of cast of external mould (C_1), posterior (C_2), dorsal (C_3), and lateral (C_4) views; note that the crescentic articulating facet of doublure is preserved. **D**. NIGP-151981, incomplete cephalo-thorax with two thoracic segments from locality 2; anterior (D_1) and dorsal (D_2) views. Scale bars 5 mm.



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Nileus sp.

Fig. 6L.

Material.—One articulated specimen minus free cheeks (repository number NIGP-152007).

Remarks.—This species resembles *Nileus petilus* Xia, 1978 from Hubei, China (see Zhou et al. 2005: pl. 3: 9, 15, 17, 21) and *Nileus huanxianensis* Zhou in Zhou et al., 1982 from Gansu, China (see Zhou and Dean 1986: pl. 60: 1–6, 8, 11) in sharing a gently curved anterior branch of facial suture and similar location of palpebral lobe. This species, however, differs in having a sagittally longer cranidial portion anterior to palpebral lobe, smaller palpebral lobe, and semi-circular pygidial outline with a slightly convex forward anterior margin. In particular, the presence of shallow anterior cranidial border and the preglabellar area that does not bend downwards indicates that this might be a new species of *Nileus*; the absence of anterior cranidial border and ventrally-curving anterior cranidium are typical of *Nileus* (see Tjernvik 1956: pl. 2: 13 for *N. limbatus* Brögger, 1882) including *N. petilus* and *N. huanxianensis*. However, more specimens are required to officially erect it as a new species.

Family Asaphidae Burmeister, 1843

Asaphidae indet.

Fig. 6K, M.

Material.—Four free cheeks and six pygidia (repository numbers: NIGP-152005, 152006).

Remarks.—These free cheeks and pygidia are of generalized asaphid type. No corresponding cranidial materials were found.

Order Corynexochida Kobayashi, 1935

Family Styginidae Vogdes, 1890

Genus *Meitanillaenus* Chang, 1974

Type species: *Meitanillaenus binodosus* Chang, 1974, from the Lower Silurian Lungmachi Formation of Meitan, Guizhou, China; by original designation.

Meitanillaenus? sp.

Fig. 6A–E.

Material.—Seven cranidia (repository numbers: NIGP-151995–151999).

Remarks.—This species, only known from cranidial material, bears morphological features that are comparable to those of *Meitanillaenus* Chang, 1974, *Failleana* Chatterton and Ludvigsen, 1976, *Sangzhiscutellum* Lin, 1987, and *Ciliscutellum* Lin, 1987. Zhou and Zhen (2008: 271) transferred all the Chinese species that had been previously assigned to *Meitanillaenus* into *Lamproscutellum* Yin, 1980, confining the stratigraphical occurrence of the former to the Silurian and the latter to the Ordovician. Cranidial morphology of *Lamproscutellum* is, however, readily distinguishable from that of *Meitanillaenus* by the presence of a paradoublural line, rounded antero-lateral corner of glabella, three distinct pairs of glabellar furrows, distinct fixigenal impression, and eye ridge (see Yin 1980: pl. 1: 4–6). The following species transferred to *Lamproscutellum* do not bear these features; *Meitanillaenus luerkouensis* Liu in Zhou et al. (1977: pl. 72: 1, 2; see also Liu 1982: pl. 229: 2, 7 and Tripp et al. 1989: fig. 8i); *Meitanillaenus flabelliforme* Liu (1982: pl. 230: 5, 6); and *Scutellum* (*Planiscutellum*) *wuxiensis* Lee (1978: pl. 107: 1, 2). From *Meitanillaenus*? sp., differs *M. luerkouensis* in having an anterior cranidial border along the entire anterior margin and lacking a glabellar crest; *M. flabelliforme* in having a longer anterior branch of facial suture and more posteriorly located palpebral lobe; *S.* (*P.*) *wuxiensis* in having a transversely wider occipital ring and more strongly divergent axial furrows.

Tripp et al. (1989) questionably transferred *Meitanillaenus luerkouensis* into *Failleana*. Lane and Siveter (1991) treated *Failleana* as a junior synonym of *Meitanillaenus* without an explanation. Chatterton and Ludvigsen (2004, see also Adrain et al. 1995) disagreed to this synonymy because *Failleana* has a wider axis, distinct ventral projection of axial furrows (called "omphalus"), and a backwardly convex posterior margin of the rostral plate. Comparison of cranidia of *Meitanillaenus*-allied species and *Failleana* (Table 3) shows that (i) *Meitanillaenus* has a narrower occipital ring (maximum transverse width 47% of width across cranidial antero-lateral corner versus 64% in *Failleana*), (ii) an exsagittally longer palpebral lobe (31% of cranidial length versus 23% in *Failleana*), and (iii) a transversely narrower glabellar constriction (39% of width across cranidial antero-lateral corner versus 50% in *Failleana*). Therefore *Meitanillaenus* should be treated as a separate genus from *Failleana*.

From cranidium of *Meitanillaenus binodosus* Chang, 1974, the type species from the Silurian of Guizhou (see Chang 1974: pl. 82: 12), all the Ordovician Chinese *Mei-*

Fig. 5. Asaphid trilobites *Remopleurides* from the Late Ordovician Xiazhen Formation near Zhuzhai, Yushan County, China. **A**, **B**, **F**–**K**, **M**. *Remopleurides xiazhenensis* sp. nov. **A**. NIGP-151982, incomplete cephalo-thorax with one thoracic segment from locality 2; dorsal (A_1), anterior (A_2), and lateral (A_3) views. **B**. NIGP-151983, articulated specimen without free cheeks from locality 2; dorsal (B_1), posterior (B_2), and lateral (B_3) views. **F**. NIGP-151984, incomplete thorax from locality 4, dorsal view. **G**. NIGP-151985, incomplete thoraco-pygidium from locality 5, dorsal view. **H**. NIGP-151986, incomplete thoraco-pygidium from locality 4, dorsal view. **I**. NIGP-151987, incomplete thoraco-pygidium from locality 2, dorsal view. **J**. NIGP-151988, incomplete thoraco-pygidium from locality 2, dorsal view. **K**. NIGP-151989, incomplete thorax from locality 2, lateral view. **M**. NIGP-151990, incomplete articulated specimen from locality 1, lateral view; note the presence of free cheek with fine terrace lines at right end. **C**–**E**, **L**. *Remopleurides* aff. *nasutus*. **C**. NIGP-151991, incomplete cephalo-thorax with eight thoracic segments from locality 2; anterior (C_1), lateral (C_2), and dorsal (C_3) views. **D**. NIGP-151992, incomplete cephalo-thorax with one thoracic segment from locality 5; dorsal (D_1), anterior (D_2), and lateral (D_3) views. **E**. NIGP-151993, incomplete cephalo-thorax with four thoracic segments from locality 5, dorsal view. **L**. NIGP-151994, incomplete cranidium from locality 2, dorsal view. Scale bars 2.5 mm. →

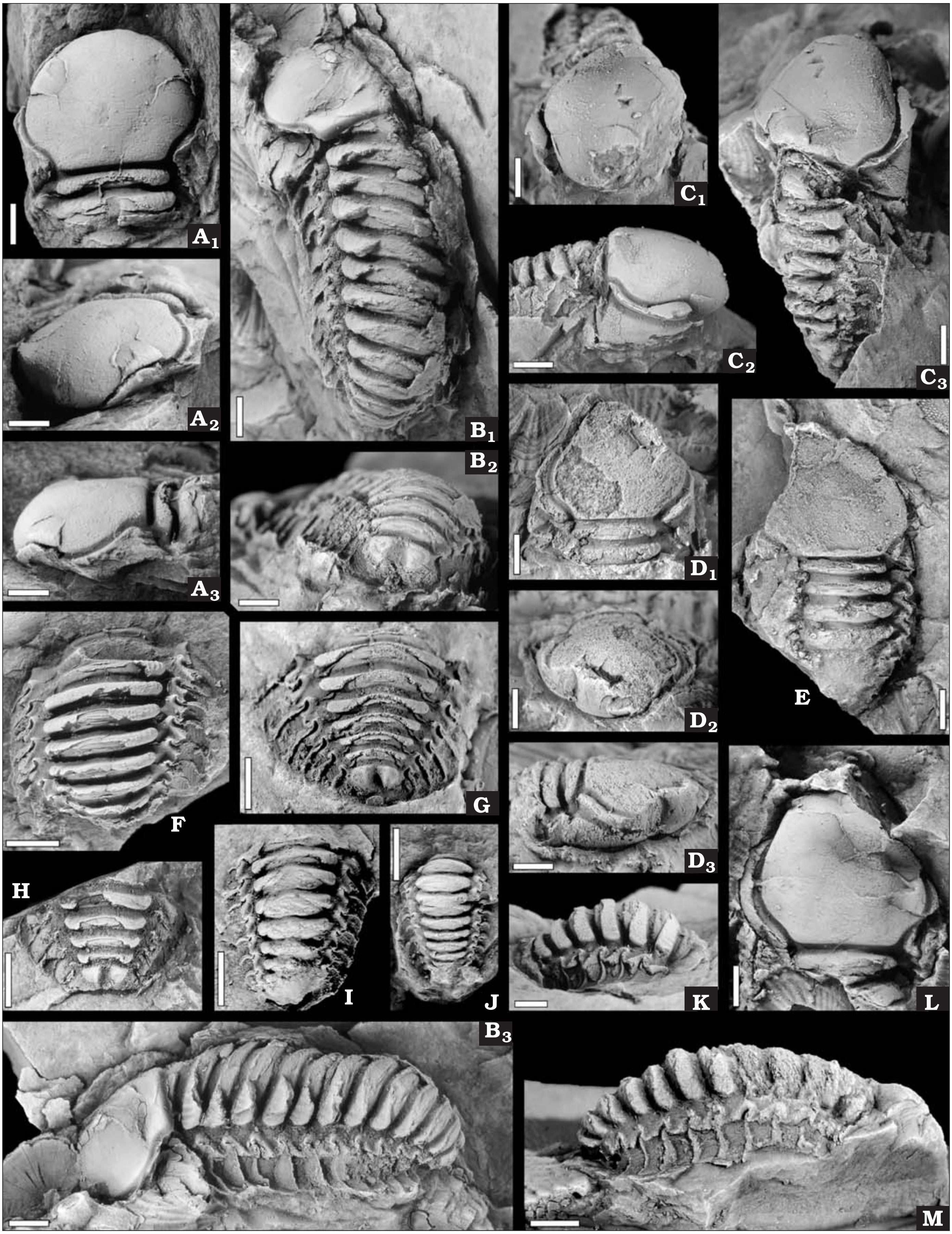

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Table 3. Comparison of *Meitanillaenus* and *Failleana*-allied taxa.

Taxon	Specimen	Glabellar construction relative to cranidial width across antero-lateral corner	Palpebral lobe length (exsag.) relative to cranidial (sag.) length	Occipital ring width relative to cranidial width across antero-lateral corner	References
Meitanillaenus? sp.	NIGP-151995	39%	29%	46%	Fig. 6A
	NIGP-151998	41%	32%	44%	Fig. 6D
	NIGP-151996	38%	28%	45%	Fig. 6B
	NIGP-151999	41%	36%	45%	Fig. 6E
	NIGP-151997	41%	35%	42%	Fig. 6C
Average	40%	32%	44%		
Meitanillaenus? *luekouensis*	31%	30%	38%	Tripp et al. (1989: fig. 8i)	
	35%	31%	46%	Zhou et al. (1977: pl. 72: 1)	
	37%	31%	46%	Liu (1982: pl. 229: 7)	
Meitanillaenus binodosus	42%	30%	54%	Yin and Lee (1978: pl. 181: 12)	
Sanzhiscutellum flabelliformes	40%	29%	45%	Liu (1982: pl. 230: 5)	
Scutellum (*Planiscutellum*) *wuxiensis*	38%	33%	52%	Lee (1978: pl. 107: 1)	
	40%	N/A	59%	Lee (1978: pl. 107: 2)	
Average	39%	31%	47%		
Failleana calva	41%	24%	61%	Chatterton and Ludvigsen (1976: pl. 6: 39)	
Failleana magnifica	52%	21%	61%	Chatterton and Ludvigsen (2004: pl. 6: 3)	
	52%	22%	69%	Chatterton and Ludvigsen (2004: pl. 6: 11)	
Failleana wangi	57%	26%	65%	Chatterton and Ludvigsen (2004: pl. 84: 9)	
Average	50%	23%	64%		
Ciliscutellum ciliensis	32%	27%	43%	Lin (1987: pl. 1: 2)	

tanillaenus-allied species differ in having an anterior cranidial border, much less distinct fixigenal impression, more distinctly impressed anterior course of axial furrows, and more sharply turned anterior branch of facial suture. It cannot be ruled out that all the Ordovician species may not be allied with *Meitanillaenus*.

Lin (1987) erected *Ciliscutellum* and *Sangzhiscutellum* from the Lower Silurian of Hunan; the type species of the latter genus is *Meitanillaenus flabelliforme*. Their cranidial architecture (Lin 1987: pls. 1, 2) greatly resembles that of the Ordovician *Meitanillaenus* species including *Meitanillaenus*? sp. described herein, except for the presence of relatively distinct eye ridge. Due to the absence of pygidial information, these Ordovician specimens from Zhuzhai cannot be confidently assigned to either genus and are questionably placed in *Meitanillaenus*.

Genus *Eokosovopeltis* Přibyl and Vaněk, 1971

Type species: *Bronteus romanovskii* Weber, 1948, from the Anderken Horizon (late Sandbian to early Katian of Ordovician), southern Kazakhstan: by original designation.

Eokosovopeltis sp.

Fig. 6G.

Material.—One pygidium (repository number NIGP-152001).

Remarks.—This pygidium bears morphologic features of *Eokosovopeltis*. Compared with pygidia of other Late Ordovician *Eokosovopeltis* species such as *E. romanovskii* (= *Bronteus romanovskii*) (Weber 1948: pl. 7: 20–23), *E. atavus* (= *Heptabronteus atavus*) (Webby 1974: pl. 28: 15–18), *E. grandicurvatus* (Edgecombe et al. 2004: fig. 5A–F), *E. currajongensis* (Edgecombe and Webby 2007: fig. 4C, D, F–I), the pygidium differs in having an inverted trapezoidal axis with a pair of longitudinal furrows, concave anterior part of the postaxial region, and slightly convex posterior part of the postaxial region with faintly impressed longitudinal furrow. Of the species, the pygidial morphology of *E. currajongensis* is most similar to this pygidium, but the former differs in having a sagittally much wider articulating half ring, faintly-defined anterior limit of postaxial region, and obliquely-directed anterior margin. To confidently erect a new *Eokosovopeltis* species to which this pygidium is assigned requires discovery of cranidial materials.

This pygidium might be associated with the styginid cranidia assigned to *Meitanillaenus*? sp. (Fig. 6A–E). However, the pygidium occurs in locality 2, whereas the cranidia occur in locality 3. Since the mudstone of each locality is not stratigraphically contemporaneous (see above), the association is considered less likely.

Eokosovopeltis cf. *currajongensis* (Edgecombe and Webby, 2007)

Fig. 6H.

Material.—One pygidium from a limestone layer above the mudstone at locality 1 (repository number NIGP-152002).

Remarks.—This pygidium differs from *Eokosovopeltis* sp. in having much narrower pleural furrows and a narrower (tr.) axial region. It is similar to pygidia of *Eokosovopeltis curra-*

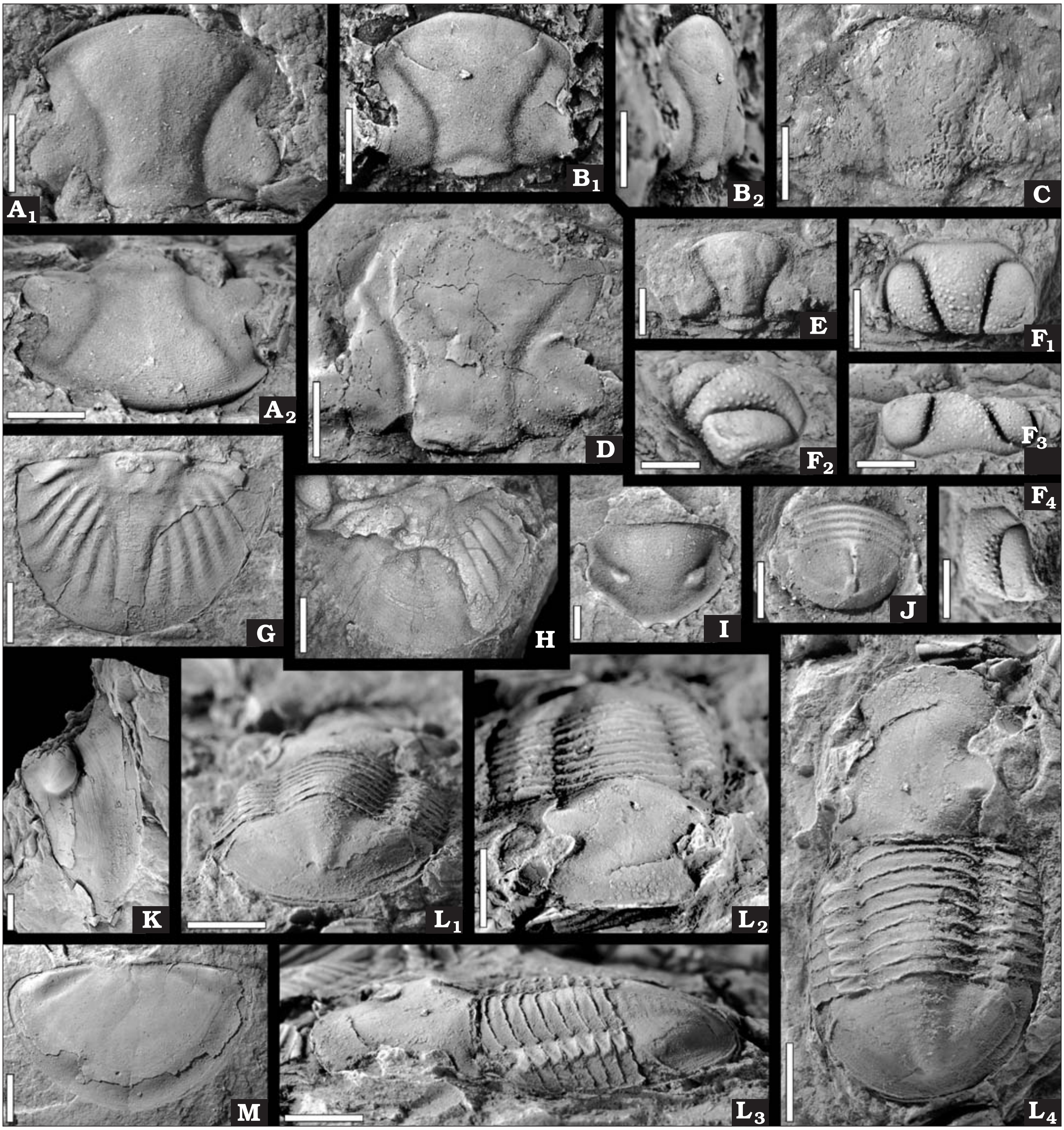

Fig. 6. Late Ordovician trilobites from Xiazhen Formation near Zhuzhai, Yushan County, China. **A**–**E**. *Meitanillaenus*? sp. **A**. NIGP-151995, cranidium from locality 3; dorsal (A_1) and anterior (A_2) views. **B**. NIGP-151996, cranidium from locality 3; dorsal (B_1) and lateral (B_2) views. **C**. NIGP-151997, cranidium from locality 3, dorsal view. **D**. NIGP-151998, cranidium from locality 3, dorsal view. **E**. NIGP-151999, cranidium from locality 3, dorsal view. **F**. *Amphilichas* sp., NIGP-152000, cranidium from locality 3; dorsal (F_1), oblique posterior (F_2), anterior (F_3), and lateral (F_4) views. **G**. *Eokosovopeltis* sp., NIGP-152001, pygidium from locality 2, dorsal view. **H**. *Eokosovopeltis* cf. *currajongensis* (Edgecombe and Webby, 2007), NIGP-152002, pygidium from a limestone layer overlying the mudstone at locality 1, dorsal view. **I**. Styginidae indet. sp. B, NIGP-152003, hypostome from locality 3, ventral view. **J**. Styginidae indet. sp. A, NIGP-152004, incomplete thoraco-pygidium with four thoracic segments from locality 3, dorsal view. **K**, **M**. Asaphidae indet. **K**. NIGP-152005, free cheek from locality 2, dorsal view. **M**. NIGP-152006, pygidium from locality 3, dorsal view. **L**. *Nileus* sp., NIGP-152007, articulated specimen minus free cheeks from locality 2; posterior (L_1), anterior (L_2), lateral (L_3), and dorsal (L_4) views. Scale bars 2.5 mm, except E, F, I 1 mm; G, H, K 5 mm.

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jongensis Edgecombe and Webby (2007: fig. 4C, D, F–I); both have seven pairs of pleural ribs. Due to poor preservation, the specific identification as *E. currajongensis* is provisional.

Styginidae indet. sp. A

Fig. 6J.

Material.—Two thoraco-pygidia (repository number NIGP-152004).

Remarks.—The sub-circular outline and absence of pygidial pleural furrows resemble *Bumastus* (see Chatterton and Ludvigsen 1976: pl. 5: 12, 37). However, the presence of distinct ridge along inner margin of marginal border is not present in *Bumastus*. These specimens may be associated with co-occurring *Meitanillaenus*? sp., since they resemble the thoraco-pygidium of *Meitanillaenus binodosus* Chang (1974: pl. 81: 6). However, they have much less distinct axial furrows and lack the antero-most pair of pleural furrows.

Styginidae indet. sp. B

Fig. 6I

Material.—Two hypostomes (repository number NIGP-152003).

Remarks.—The hypostomes are of styginid (e.g., see Whittington 1988: fig. 9 for *Bumastus*). They are characterized by a more pentagonal outline and a pair of short, closely-spaced spines along posterior margin. The hypostomes may be associated with co-occurring *Meitanillaenus*? sp.

Order Harpetida Whittington, 1959

Family Harpetidae Hawle and Corda, 1847

Genus *Hibbertia* Jones and Woodward, 1898

Type species: *Harpes flanaganni* Portlock, 1843 from the Caradocian (Late Ordovician) Bardahessiagh Formation of Pomeroy, Tryone County, Northern Ireland.

Hibbertia aodiensis sp. nov.

Figs. 3B, 7A–D, F, G.

Etymology: After Aodi, a small village next to Zhuzhai.

Holotype: NIGP-152011, incomplete cephalon from locality 2.

Type locality: Locality 2, about 60 m northwest of Zhuzhai, Yushan County. GPS coordinate is 28°34'23.27" N and 118°20'16.50" E.

Type horizon: Xiazhen Formation, Upper Ordovician, *Dicellograptus complexus* Graptolite Zone.

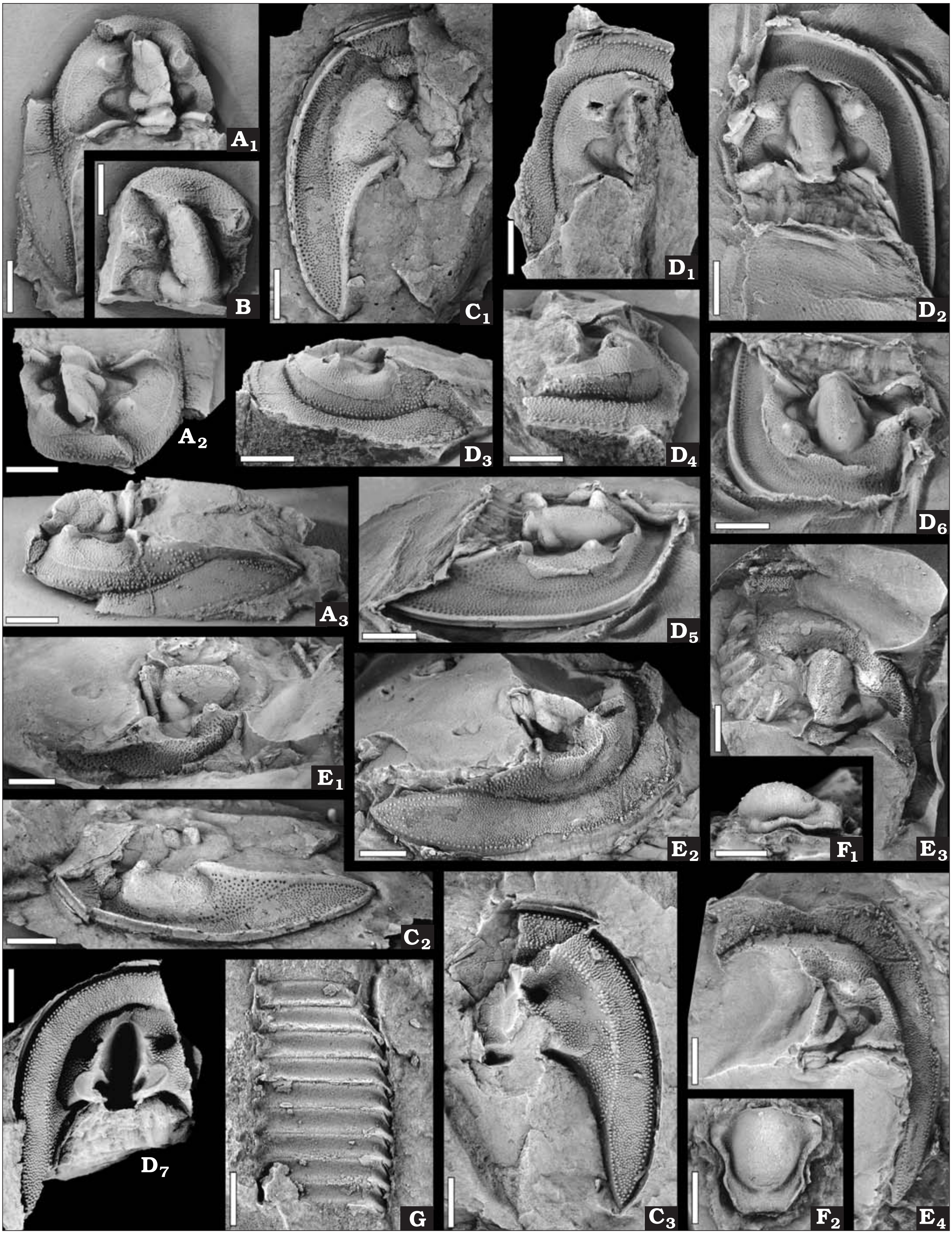
Material.—Four cephala and one hypostome (repository numbers: NIGP-152008–152013).

Diagnosis.—Species of *Hibbertia* with a longer (sag.) glabella, brim that is narrow, deep, flat-bottomed, and lower-leveled ala, and lacking interalar furrow.

Description.—Cephalon minus prolongation semi-circular in outline; cephalic and prolongation length nearly equal. External rim strongly vaulted. Brim narrow, deep and nearly flat-bottomed; sagittal length about one-fifth of cephalic length. Genal roll slightly convex outwards and steeply down-sloping. Girder deeply impressed and extends to mid-point of prolongation. Girder kink weakly developed. Inner margin of fringe runs parallel to genal roll and then strongly curved inwards to merge into internal rim; the margin expressed by moderately raised ridge which corresponds to distal limit of caeca on genal area. Anterior boss and preglabellar depression absent. Transverse preglabellar ridge weakly developed. Glabella strongly vaulted and bullet-shaped, with maximal sagittal length being 54% of cephalic length. Axial furrow deep and moderately wide, narrowing forwards. Three pairs of glabellar furrows present; S1 straight, deeply incised and obliquely directed backwards; S2 short and anteriorly directed; S3 short (but longer than S2) and anteriorly directed. L1 convex and sub-triangular in outline. S0 wide and shallow, with deeply impressed distal end; L0 strongly convex, and anterior margin curved forwards; small sagittal node present. Palpebral lobe highly raised. Eye small and located at anterior 35% of glabellar sagittal length; distal end located at the same exsagittal line as that of ala. Eye ridge moderately developed and slightly obliquely directed backwards. Ala semi-circular in outline, moderately convex, and much lower than genal area; maximum width 75% and maximum length 40% of corresponding glabellar dimension. Alar ridge weakly developed, follows axial furrow, and ends immediately posterior to adaxial end of eye ridge. Alar furrow steep-sided, deep and wide, becoming shallower and narrower forwards. Interalar furrow and alar depression absent. Internal rim strongly raised, becomes narrow adaxially, and extends posteriorly to meet external rim.

Brim ornamented with one or two rows of large pits along distal extremity and girder, and anastomosing caeca at bottom; pits along distal extremity larger than those along girder; genal roll with smaller pits (pits become larger towards girder); genal area with anastomosing caeca; glabella with weakly developed caeca along crest (only observed in external mold); pits on brim and genal roll become larger posteriorly; caeca on genal area form distinct ridge that runs anteriorly from proximal end of eye ridge, gently convex outwards, and abruptly stops at inner margin of fringe, and runs posteriorly from palpebral lobe, gently convex outwards, and then smoothly merged into inner margin of fringe.

Fig. 7. Late Ordovician trilobites from Xiazhen Formation near Zhuzhai, Yushan County, China. **A–D**, **F**, **G**. *Hibbertia aodiensis* sp. nov. **A**. NIGP-152008, incomplete cephalon from locality 2; dorsal (A_1), anterior (A_2), lateral (A_3) views. **B**. NIGP-152009, incomplete cephalon from locality 2, dorsal view. **C**. NIGP-152010, incomplete cephalon from locality 2; dorsal (C_1) and lateral (C_2) views of cast of external mould, and ventral view (C_3). **D**. NIGP-152011, holotype, incomplete cephalon from locality 2; dorsal (D_1), lateral (D_3), and anterior (D_4) views of internal mould, dorsal (D_2), lateral (D_5), and anterior (D_6) views of cast of external mould, and ventral view of external mould (D_7). **F**. NIGP-152012, hypostome from locality 2; lateral (F_1) and ventral (F_2) views. **G**. NIGP-152013, incomplete thoracic segments from locality 2, dorsal view. **E**. *Scotoharpes* sp., NIGP-152014, incomplete cephalon from locality 4; lateral (E_1) and dorsal (E_3) views of cast of external mould, and lateral (E_2) and dorsal (E_4) views of internal mould. Scale bars 5 mm, except F, G 2.5 mm. →



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Hypostome as wide as long. Anterior lobe of middle body convex and sub-circular in outline; posterior lobe small and crescentic in outline; sagittal length of posterior lobe 20% of hypostomal sagittal length. Anterior margin gently convex forwards; lateral margin straight at antero-lateral portion, gently curved inwards at mid-point of hypostomal length, projected outwards opposite anterior end of posterior lobe, and then runs straight and obliquely posteriorly; posterior margin slightly curved forwards. Anterior border widens abaxially and narrows to disappear absent adaxially; lateral border rimmed, and of consistent thickness; lateral border furrow moderately deep, but shallows out posteriorly. Middle furrow shallows out adaxially. Macula indistinct.

Thoracic pleura straight with shallow and wide pleural furrow that continues into pleural spine.

Remarks.—Of *Hibbertia* species (Ebach and McNamara 2002), *Hibbertia aodiensis* sp. nov. is similar to *H. inghami* (= *Paraharpes inghami*) (Owen 1981: pl. 7: 21–24, pl. 8: 1) from Norway. Both share a flat-bottomed brim with large-pitted distal and proximal extremities, two caecal ridges on genal area (one that runs anteriorly from proximal end of eye ridge and the other that runs diagonally from palpebral lobe), and the same ornamentation pattern in the brim, genal roll and genal area. However, this new species differs in having a longer (sag.) glabella, narrower (sag.) brim, taller external rim, much distinct inner margin of fringe, taller genal roll, and less elevated ala, and lacking an interalar furrow. *Hibbertia ottawaensis* (Billings, 1865) from Canada (see Shaw 1968: pl. 6: 18) bears the similar glabellar morphology with regard to its sagittal length. However, it shares such features as elevated ala and interalar furrow with other *Hibbertia* species, which are not present in *H. aodiensis*.

Stratigraphic and geographic range.—Late Ordovician and Jiangxi Province, South China.

Genus *Scotoharpes* Lamont, 1948

Type species: *Scotoharpes domina* Lamont, 1948 from the Llandovery (Early Silurian) of Scotland.

Scotoharpes sp.

Fig. 7E.

Material.—One cephalon (repository number NIGP-152014).

Remarks.—This incomplete cephalon is distinguished from the co-occurring *Hibbertia aodiensis* sp. nov. in having a wider cephalon, shorter (sag.), smaller, sub-rectangular glabella, longer (sag.) area of genal roll plus genal area, strongly obliquely-directed eye ridge (posteriorly located eye accordingly), wider (tr.) ala, and triangular area with faintly-developed caeca located postero-laterally diagonal to the ala. The larger ala, oblique eye ridge and posteriorly located eye indicate that this cranidium is associated with *Scotoharpes*; compare with *Scotoharpes domina* Lamont (1948: pl. 1: 2 and see also Norford 1973: pl. 1: 1–3).

Order Lichida Moore, 1959

Family Lichidae Hawle and Corda, 1847

Genus *Amphilichas* Raymond, 1905

Type species: *Platymetopus lineatus* Angelin, 1854 from the Ashgillilan Boda Limestone of Sweden; by monotypy.

Amphilichas sp.

Fig. 6F.

Material.—One cranidium (repository number NIGP-152000).

Remarks.—*Amphilichas* from Tasmania (Edgecombe et al. 2004: fig. 11A–C; Edgecombe and Webby 2007: fig. 5B–D) shows resemblance to this cranidium. This incomplete glabella however differs in having an anterior margin that is slightly curved backwards sagittally and sharply curved longitudinal furrows. The specific identification cannot be completed, because of incomplete preservation as well as paucity of specimens.

Order Phacopida Salter, 1864

Family Calymenidae Milne Edwards, 1840

Subfamily Reedocalymeninae Hupé, 1955

Genus *Vietnamia* Kobayashi, 1960

Type species: *Calymene douvillei* Mansuy, 1908, from the Na Mo Formation (Middle to Upper Ordovician), Thai Nguyen, Vietnam; by original designation.

Vietnamia yushanensis sp. nov.

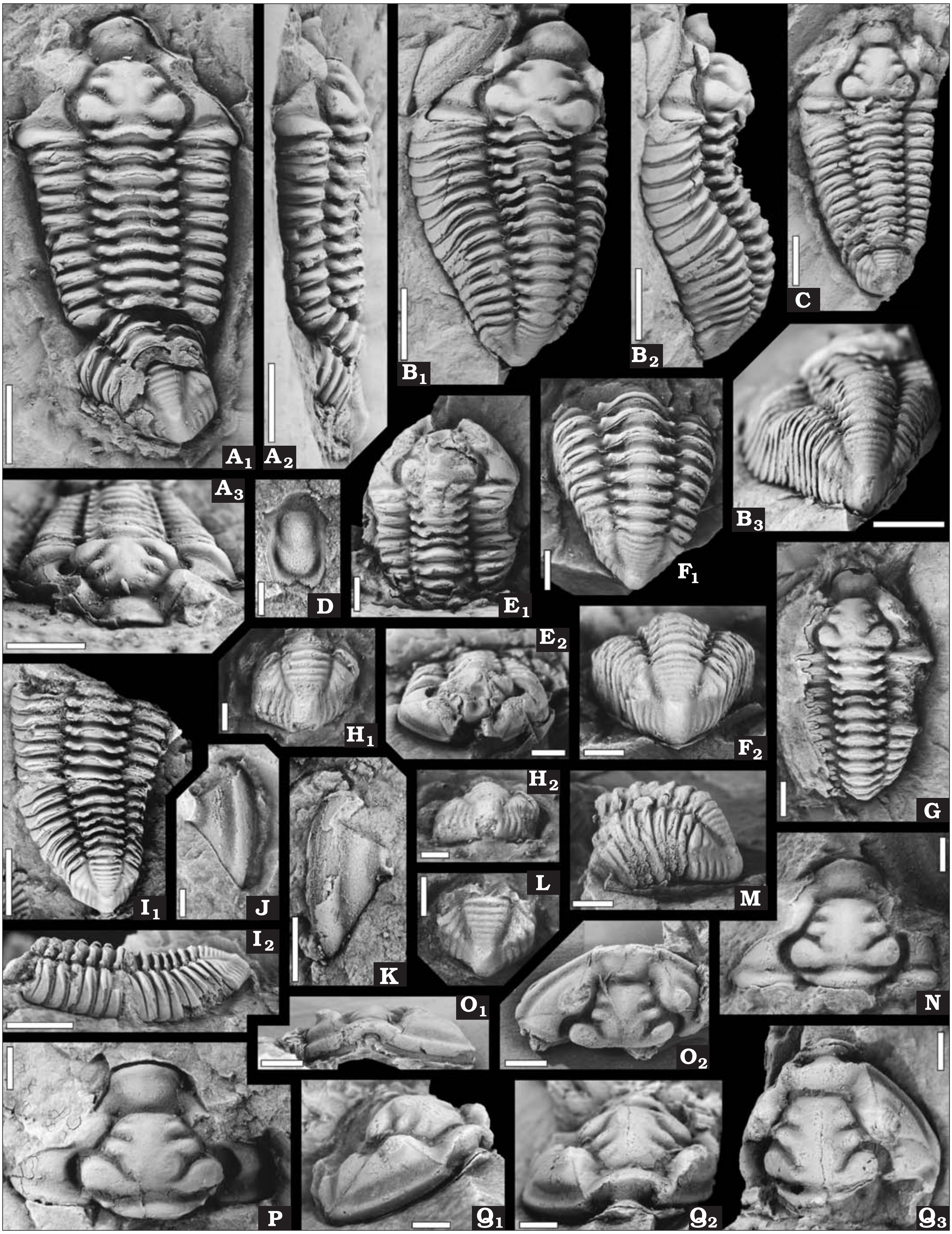
Figs. 3C, 8A–G, I–N, P, 9B, E, H, I, N.

Etymology: After Yushan county where the sampling localities are located.

Holotype: NIGP-152032, articulated specimen from locality 2, 2 cephala, 21 cranidia, 14 thoraces, six pygidia, five free cheeks, and one hypostome.

Type locality: Locality 2, about 60 m northwest of Zhuzhai, Yushan County. GPS coordinate is 28°34'23.27" N and 118°20'16.50" E.

Fig. 8. Late Ordovician trilobites from Xiazhen Formation near Zhuzhai, Yushan County, China. All specimens are from locality 2, except NIGP-152042 (L) which is from locality 1. **A–G**, **I–N**, **P**. *Vietnamia yushanensis* sp. nov. **A**. NIGP-152032, holotype, articulated specimen without free cheeks; dorsal (A_1), lateral (A_2), and anterior (A_3) views. **B**. NIGP-152033, articulated specimen with the dislocated left free cheek; dorsal (B_1), lateral (B_2), and posterior (B_3) views. **C**. NIGP-152034, articulated specimen without free cheeks, dorsal view. **D**. NIGP-152035, hypostome, ventral view. **E**. NIGP-152036, cephalo-thorax with hypostome in place; dorsal (E_1) and anterior (E_2) views. **F**. NIGP-152037, thoraco-pygidium; dorsal (F_1) and posterior (F_2) views. **G**. NIGP-152038, articulated specimen, dorsal view. **I**. NIGP-152039, thoraco-pygidium; dorsal (I_1) and lateral (I_2) views. **J**. NIGP-152040, right free cheek, dorsal view. **K**. NIGP-152041, left free cheek, dorsal view. **L**. NIGP-152042, pygidium, dorsal view. **M**. NIGP-152043, thoraco-pygidium, lateral view. **N**. NIGP-152044, cranidium, dorsal view. **P**. NIGP-152045, cranidium, dorsal view. **H**. *Vietnamia* sp. E, NIGP-152029, pygidium; dorsal (H_1) and posterior (H_2) views. **O**. *Vietnamia*? sp., NIGP-152030, incomplete cephalon; anterior (O_1) and dorsal (O_2) views; note the presence of strongly arched, transversely elongated rostral plate. **Q**. *Vietnamia* sp. A, NIGP-152031, cephalon; oblique anterior (Q_1), anterior (Q_2), and dorsal (Q_3) views; note the presence of upside down anvil-shaped rostral plate. Scale bars 2.5 mm, except A, B, C, I 5 mm; D, H, J, N 1 mm. →



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Type horizon: Xiazhen Formation, Upper Ordovician, *Dicellograptus complexus* Graptolite Zone.

Material.—Seven articulated exoskeletons, four cephalo-thoraces, 12 thoraco-pygidia, two cephala, 21 cranidia, 14 thoraces, six pygidia, five free cheeks, and one hypostome (repository numbers: NIGP-152032–152045, 152050, 152052–152054, 152056).

Diagnosis.—Species of *Vietnamia* with distinct pygidial lateral and posterior edge anterior to cincture, seven pygidial axial rings, anterior node in fossula, and lower-leveled area between L1.

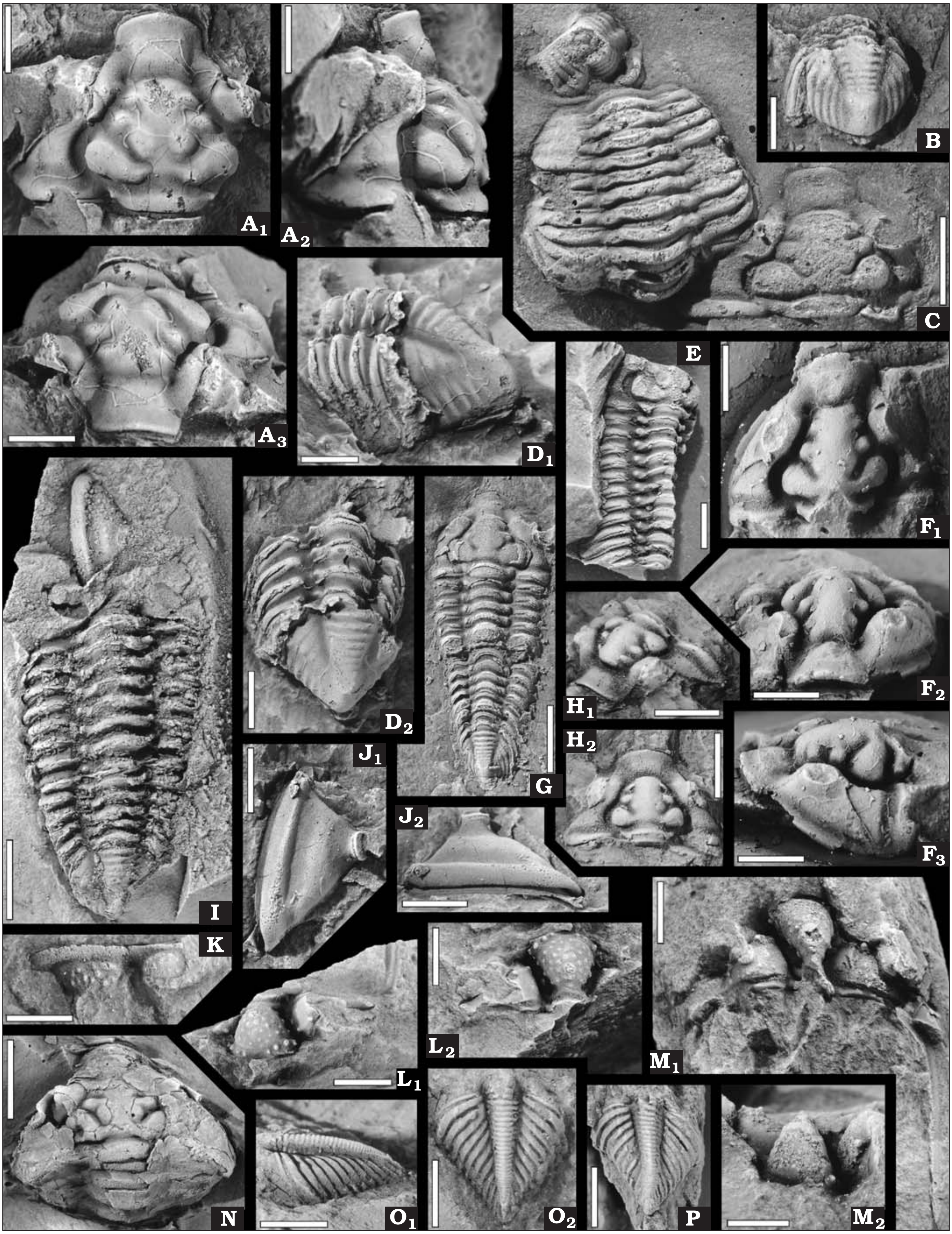
Description.—Dorsal exoskeleton elliptical in outline. Cephalon semi-circular in outline. Cranidium sub-triangular in outline with pointed (sag.) anterior margin, and sagittal length 60% of transverse width. Anterior cranidial border nearly flat and weakly arched dorsally; anterior cranidial border furrow shallow and broad, and moderately deepens distally. Preglabellar area moderately convex; anterior furrow shallow and wide, and divergent forwards at about 30° from sagittal line; preglabellar furrow deeper than anterior furrow. Fossula distinctively depressed, and located diagonal to S3, immediately outside axial and anterior furrows, and immediately anterior to eye ridge; anterior node small but distinct and positioned at adaxial slope of fossula. Eye ridge moderately developed, and abruptly narrows as crossing axial furrows. Axial furrow wide and deep, and progressively wider and deeper posteriorly, with maximum width and depth opposite L1; axial furrow opposite L1 steep-sided and flat-bottomed. Glabella trapezoidal in outline, anterior margin straight to slightly convex forwards, and sagittal length 63% of maximum transverse width across L1. Three pairs of glabellar furrows present; abaxial end of all three pairs positioned within palpebral area of fixigenae. S3 obliquely directed backwards, weakly incised, and shortest. S2 slightly more oblique and weakly bifurcated. S1 deeply impressed, strongly obliquely directed posteriorly, and bifurcated at mid-length adaxially; anterior branch shorter and more weakly impressed, and proximal one-quarter of posterior branch shallow and gently curved forwards. L1 elongated (tr.), moderately convex, strongly inflated abaxially, tapers adaxially, abaxial edge overhangs axial furrows, and posterior margin weakly sinuous; adaxial one-third gently slopes down and then slightly raised sagittally, and node weakly developed at adaxial one-third. L2 and L3 sub-rectangular and raised as pointed node in central area. Intermediate lobe subcircular in outline, weakly convex, well delineated posteriorly and abaxially by posterior branch of S1, and remaining boundaries poorly defined by weakly impressed furrows. Palpebral lobe crescentic in outline and mid-point located opposite S2. Occipital furrow moderately curved forwards following posterior margin of L1 and abruptly becomes shallower sagittally from adaxial two-thirds of its course. Occipital ring progressively widens adaxially; distal end protruded as distinct node. Preocular area of fixigenae gently slopes downwards; palpebral area steeply slopes; postocular area triangular in outline and gently slopes distally. Posterior cranidial border furrow shallow and broad, and slightly curved forwards at its midlength. Anterior branch of facial suture slightly convex laterally and moderately convergent forwards in posterior half; anterior half runs straight and parallel-sided, and then sharply curved inwards; posterior branch runs transversely and then gently curved backwards, and cuts postero-lateral cephalic corner, forming gonatoparian suture.

Librigena with blunted postero-lateral end. Eye socle weakly developed and eye socle furrow shallow. Librigenal field gently slopes downwards in adaxial two-thirds and then steeply slopes. Librigenal lateral border furrow moderately deep and continues into anterior furrow and anterior cranidial border furrow; librigenal lateral border sharply inturned.

Hypostome elliptical in outline. Anterior margin strongly convex forwards. Posterior and lateral borders moderately convex; posterior and lateral border furrows deep but shallow out at anterior end of posterior lobe; posterior border projected as spine of moderate length. Anterior lobe sub-circular in outline; posterior lobe crescentic in outline and larger than anterior lobe. Middle furrow deep and shallows adaxially.

Thorax of 13 segments. Axis gently tapers backwards and occupies about 45% of thoracic width. Axial furrow relatively wide and deep, deepening as pit at posterior end in each segment. Axial ring slightly curved forwards medially; distal end moderately curved forwards and protruded as distinct node. Articulating furrow deep and wide in distal half and shallows and narrows in proximal half. Anterior and posterior pleural band of equal width, and strongly convex; small fulcral process located at proximal one-third (or mid-length at dorsal view) of posterior band; the processes be-

Fig. 9. Late Ordovician trilobites from Xiazhen Formation near Zhuzhai, Yushan County, China. **A**, **D**, **J**. *Vietnamia* sp. B. **A**. NIGP-152046, cranidium from locality 4; dorsal (A_1), lateral (A_2), and anterior (A_3) views. **D**. NIGP-152051, incomplete thoraco-pygidium from locality 4; lateral (D_1) and dorsal (D_2) views. **J**. NIGP-152055, left free cheek from locality 4; dorsal (J_1) and lateral (J_2) views. **C**. *Vietnamia* sp. E, NIGP-152047, dislocated cranidium, thoracic segments, and pygidium from locality 5, dorsal view. **G**. *Vietnamia* sp. D, NIGP-152049, articulated specimen from locality 4, dorsal view. **B**, **E**, **H**, **I**, **N**. *Vietnamia yushanensis* sp. nov. **B**. NIGP-152050, pygidium with two thoracic segments from locality 3, dorsal view. **E**. NIGP-152052, incomplete cephalon-thorax from locality 5, dorsal view. **H**. NIGP-152053, cranidium from locality 3; oblique anterior (H_1) and dorsal (H_2) views. **I**. NIGP-152054, thoraco-pygidium with dislocated free cheek from locality 4, dorsal view. **N**. NIGP-152056, enrolled articulated specimen from locality 4, cast of external mould, dorsal view; note the granules on the surface. **F**. *Vietnamia* sp. C, NIGP-152048, incomplete cephalon from locality 1; dorsal (F_1), anterior (F_2), and lateral (F_3) views. **K–M**, **O**, **P**. *Erratencrinurus* aff. *trippi*. **K**. NIGP-152057, left free cheek from locality 1, lateral view. **L**. NIGP-152058, cranidium from locality 1; anterior (L_1) and dorsal (L_2) views. **M**. NIGP-152059, cranidium from locality 1; dorsal (M_1) and anterior (M_2) views. **O**. NIGP-152060, pygidium from locality 1; lateral (O_1) and dorsal (O_2) views. **P**. NIGP-152061, pygidium from locality 1, dorsal view. Scale bars 2.5 mm, except B 1 mm; I, N 5 mm. →



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come progressively closer to axial furrow posteriorly; pleural furrow straight, deep and wide, becoming shallow and narrow distally. Articulating facet developed from mid-length of pleural band and abruptly widens distally at distal one-third of pleural length.

Pygidium triangular in outline. Axis occupies about 54% of maximum transverse pygidial width; axial furrow straight or slightly convex laterally; axis moderately tapers backwards. Seven axial rings present; terminal piece parabolic in outline, flat, and moderately protruded upwards in posterior end; inter-ring furrow progressively shallower posteriorly; postaxial ridge moderately convex and laterally delineated by shallow furrow which is apparently continuous into axial furrows. Five pairs of pleural furrows moderately impressed; posteriormost furrow separates terminal piece and posteromost pleural rib; pleural rib abruptly bent downwards along lateral and posterior edge of triangular pleural field; the edge moderately protruded outwards, and the lower limit represents cincture; pleural field distal to the edge nearly vertical.

Dorsal exoskeleton covered with fine granules. Some specimens enrolled.

Remarks.—The concept of *Vietnamia* has recently been revised by Turvey (2005); most features listed in the emended diagnosis are observed in this species. *Vietnamia yushanensis* sp. nov. is characterized by a distally protruding lateral and posterior pygidial edge that is immediately anterior to the cincture, seven pygidial axial rings, an anterior node in the fossula, and the absence of pygidial interpleural furrows. The presence of small morphologic features such as the anterior node cannot be confirmed from the illustrations of other species. However, the pygidial features ensure that it is a new species of *Vietnamia*.

Zhou and Zhen (2008: 241) transferred a few species from China previously assigned to *Neseuretus* into *Vietnamia*. *Neseuretus abnormis* Li, 1988 (Li 1988: pl. 1: 8, pl. 2: 4–7) from Tibet was erected based on a poorly preserved cranidium and four pygidia; Turvey (2005) concluded that it is a probable junior synonym of *Vietnamia nivalis* (Salter, 1865); the pygidial morphology does accord with that of *V. nivalis* (see Turvey 2005: pl. 4: 6, 10). Liu et al. (1991: pl. 17: 6) illustrated *Neseuretus* (*Neseuretinus*) *henanensis* Chang from Henan. The poorly-preserved cranidium exhibits more resemblance to *Vietnamia* than to *Neseuretinus* in having a truncated anterior glabellar margin and laterally inflated L1. Assignment of *Neseuretus* (*Neseuretinus*) sp. from Xinjiang (Lin et al. 1990: pl. 6: 1, 2) to *Vietnamia* appears questionable, because the pygidium is of *Calymenesun* or *Reedocalymene* in having a distinct cincture and narrower (tr.), posteriorly-tapering postaxial region, although the cranidium resembles that of *V. nivalis*.

Like many calymenid taxa, *Vietnamia yushanensis* sp. nov. has 13 thoracic segments, which is the first documentation for the genus. *V. yushanensis* has an anterior node in the fossula (see Fig. 8A_1, B_1, P) which is also observed in *Reedocalymene* and *Calymenesun* (Peng et al. 2000); the node is smaller than that of other taxa. *Vietnamia douvillei* (Mansuy, 1908), the type species appears to have the node (see Turvey 2005: pl. 3: 5; a small node appears to be present on the left fossula).

Stratigraphic and geographic range.—Late Ordovician and Jiangxi Province, South China.

Vietnamia sp. A

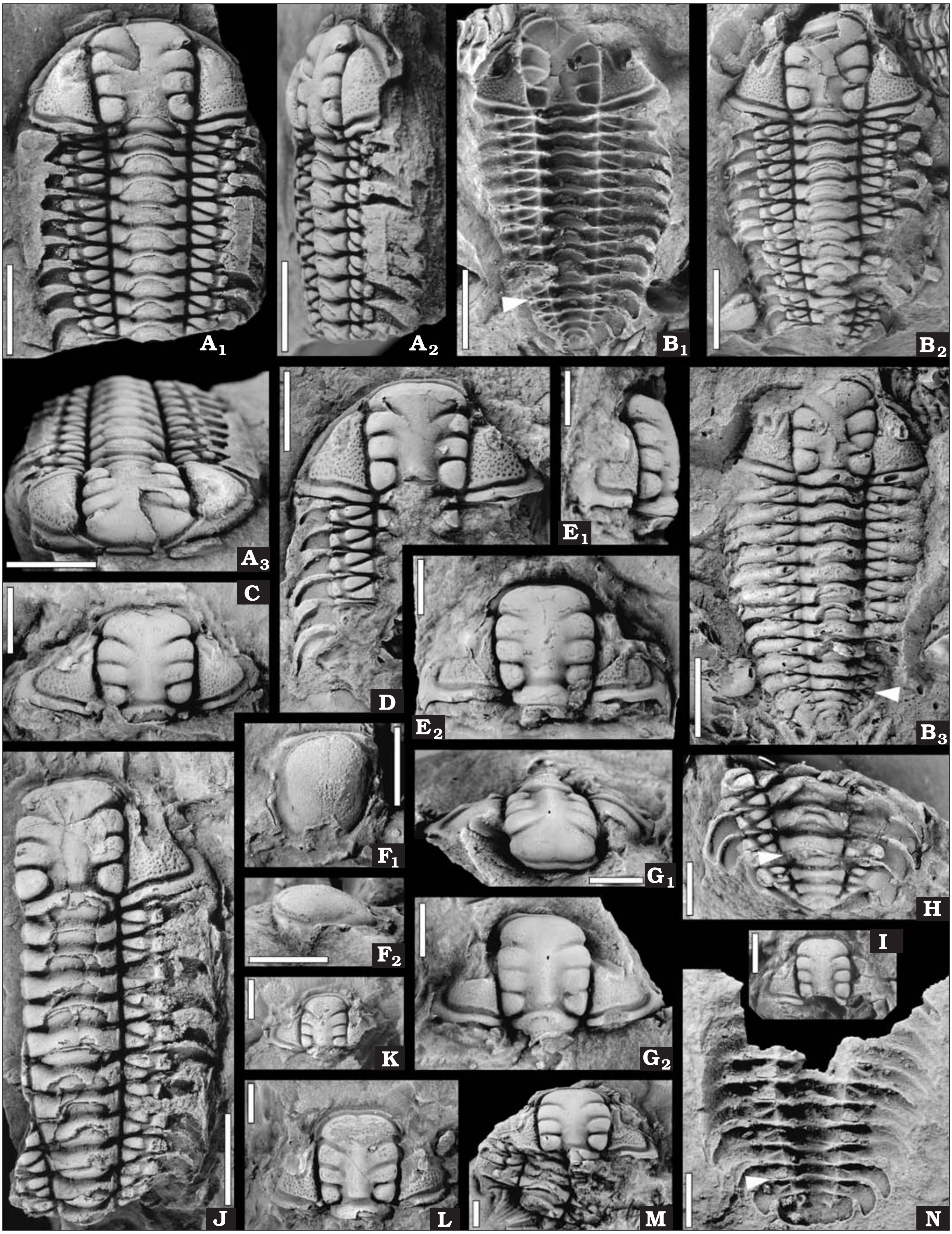
Fig. 8Q.

Material.—One incomplete cephalon (repository number NIGP-152031).

Remarks.—This species differs from co-occurring *Vietnamia yushanensis* sp. nov. in having a strongly dorsally arched anterior cephalic margin, posterior cranidial border furrow that is smoothly curved forwards distally, moderately convex sagittal area between L1, more weakly developed intermediate lobe, and truncated anterior glabellar margin. The dorsal flexure of the anterior cephalic margin of this species is the strongest of the *Vietnamia* species described herein.

Turvey (2005: pl. 4: 2) illustrated a rostral plate of *Vietnamia douvillei* (Mansuy, 1908). The impression of the rostral plate of *Vietnamia yushanensis* sp. nov. (Fig. 8Q_1, Q_2) accords with the morphology of *V. douvillei*; a fissure in the middle of left half (Fig. 8Q_2) represents a connective suture. The upside down anvil-shaped rostral plate of *Vietnamia* differs from *Neseuretus* (see Whittington 1966: pl. 5: 5, 6, 8, 10; Hammann 1983: pl. 4: 39b) in being laterally bounded by less divergent connective sutures, and from *Calymenesun* and *Reedocalymene* (see Peng et al. 2000: text-fig. 1A–E, pl. 3: 1–3) in having a doublure sector that is much wider (tr.) than the border sector.

Fig. 10. Cheirurid trilobite *Remopleurides xiazhenensis* sp. nov. from the Late Ordovician Xiazhen Formation near Zhuzhai, Yushan County, China. → **A**. NIGP-152015, incomplete articulated specimen minus two thoracic segments and pygidium from locality 2; dorsal (A_1), lateral (A_2), and anterior (A_3) views; note the presence of pits on fixigenal and librigenal field. **B**. NIGP-152016, holotype, articulated specimen from locality 2; ventral view of external mould (B_1), dorsal view (B_2), and dorsal view of cast of external mould (B_3); note the presence of densely-distributed granules and the arrow in B_1 and B_3 points the boundary between thorax and pygidium. **C**. NIGP-152017, cranidium from locality 2, dorsal view; note the presence of a pair of small pits on L4 (see also Fig. 10M and I). **D**. NIGP-152018, incomplete articulated specimen from locality 2, dorsal view. **E**. NIGP-152019, cranidium from locality 2; lateral (E_1) and dorsal (E_2) views. **F**. NIGP-152020, provisionally associated hypostome from locality 4; ventral (F_1) and lateral (F_2) views. **G**. NIGP-152021, cranidium from locality 2; anterior (G_1) and dorsal (G_2) views. **H**. NIGP-152022, thoraco-pygidium with four thoracic segments from locality 2, dorsal view; the arrow indicates the boundary between thorax and pygidium. **I**. NIGP-152023, cranidium from locality 2, dorsal view. **J**. NIGP-152024, articulated specimen minus pygidium from locality 4, dorsal view. **K**. NIGP-152025, cranidium from locality 4, dorsal view. **L**. NIGP-152026, cranidium from locality 4, dorsal view. **M**. NIGP-152027, disarticulated cephalon and four thoracic segments from locality 2, dorsal view. **N**. NIGP-152028, external mould of incomplete thoraco-pygidium from locality 2, ventral view; note the absence of articulating half ring that confirms the boundary between thorax and pygidium indicated by the arrow. Scale bars 2.5 mm, except A, B, D, J 5 mm.



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Vietnamia sp. B

Fig. 9A, D, J.

Material.—One cranidium, thoraco-pygidium, and free cheek (repository numbers: NIGP-152046, 152051, 152055).

Remarks.—The cranidium differs from other co-occurring *Vietnamia* species in having a very strongly developed intermediate lobe, more strongly depressed sagittal area between most strongly elongated (tr.) L1, relatively longer (sag.) preglabellar area, and more laterally convex posterior half of anterior branch of facial suture. The pygidium also differs in having shallower inter-ring furrows and pleural furrows.

Vietnamia sp. C

Fig. 9F.

Material.—One incomplete cephalon (repository number NIGP-152048).

Remarks.—This incomplete cephalon, although seemingly compressed laterally, differs from other *Vietnamia* species in having a rounded anterior cranidial margin, anterior glabellar margin that is indented medially, and weakly developed intermediate lobe.

Vietnamia sp. D

Figs. 9G, 11V.

Material.—One articulated specimen and two pygidia (repository numbers: NIGP-152049, 152083).

Remarks.—This species is distinguished by its rounded anterior glabellar margin, faintly developed intermediate lobe, and weakly convex pygidium, and less distinct pleural edge. In particular, the rounded anterior glabellar margin is not found in any *Vietnamia* species from the Xiazhen Formation. The articulated specimen (Fig. 9G) appears to be dorso-ventrally compressed, and its pygidial features, although flattened, are comparable to those of *Vietnamia yushanensis* sp. nov.

Vietnamia sp. E

Figs. 8H, 9C.

Material.—One disarticulated specimen and two pygidia (repository numbers: NIGP-152029, 152047).

Remarks.—This species is distinguished by its anterior cranidial margin that is not pointed, cincture expressed as a narrow furrow, pygidial pleural furrows which maintain their depth as crossing cincture (become shallower and obscure in *Vietnamia yushanensis* sp. nov.; see Fig. 8F), and less distinct lateral and posterior edge anterior to cincture.

Vietnamia? sp.

Fig. 8O.

Material.—One incomplete cephalon (repository number NIGP-152030).

Remarks.—The morphology of L1, intermediate lobe, course of facial suture of this species resemble those of *Calymenesun tingi* (Sun, 1931) (see Lu 1975: pl. 46: 13; Peng et al. 2000: text-fig. 1A). This species has a longer (exsag.) palpebral lobe and wider (tr.) preglabellar area. It cannot be confirmed whether it has a pre-cranidial spine as does *Calymenesun*. It is the rostral plate that evidently differentiates this species from *Calymenesun*. The rostral plate is wide (tr.) and strongly arched dorsally (Fig. 8O_1), whereas that of *Calymenesun* (see Peng et al. 2000: text-fig. 1B–E) is much smaller and not arched dorsally. In addition, the rostral plate is located more anteriorly and dorsally than that of *Calymenesun* which is entirely ventral. With regard to the morphology and position, the rostral plate of this species is similar to that of *Neseuretus* (see Hammann 1983: pl. 4: 39b; Rabano 1990: pl. 14: 6, pl. 15: 2, 10) and *Calymene* (see Chatterton and Ludvigsen 2004: pl. 54: 1–4).

Compared to *Vietnamia* sp. A (compare Fig. 8O_2 and Q_3), this species has a more flattened cephalon, and more strongly laterally inflated L1. The rostral plate morphology is much different. *Vietnamia* sp. A has a doublure sector that is wider (tr.) than border sector; *Calymene* (see Chatterton and Ludvigsen 2004: pl. 54: 4) and *Flexicalymene* (see Evitt and Whittington 1953: pl. 9: 4–6) whose overall morphology of rostral plate is similar to this species, have a doublure sector that is narrower (tr.) than border sector. Such mixture of characters prevents the author from confidently placing this species in any of the above-mentioned genera, but the glabellar configuration leads to questionably associate it with *Vietnamia*.

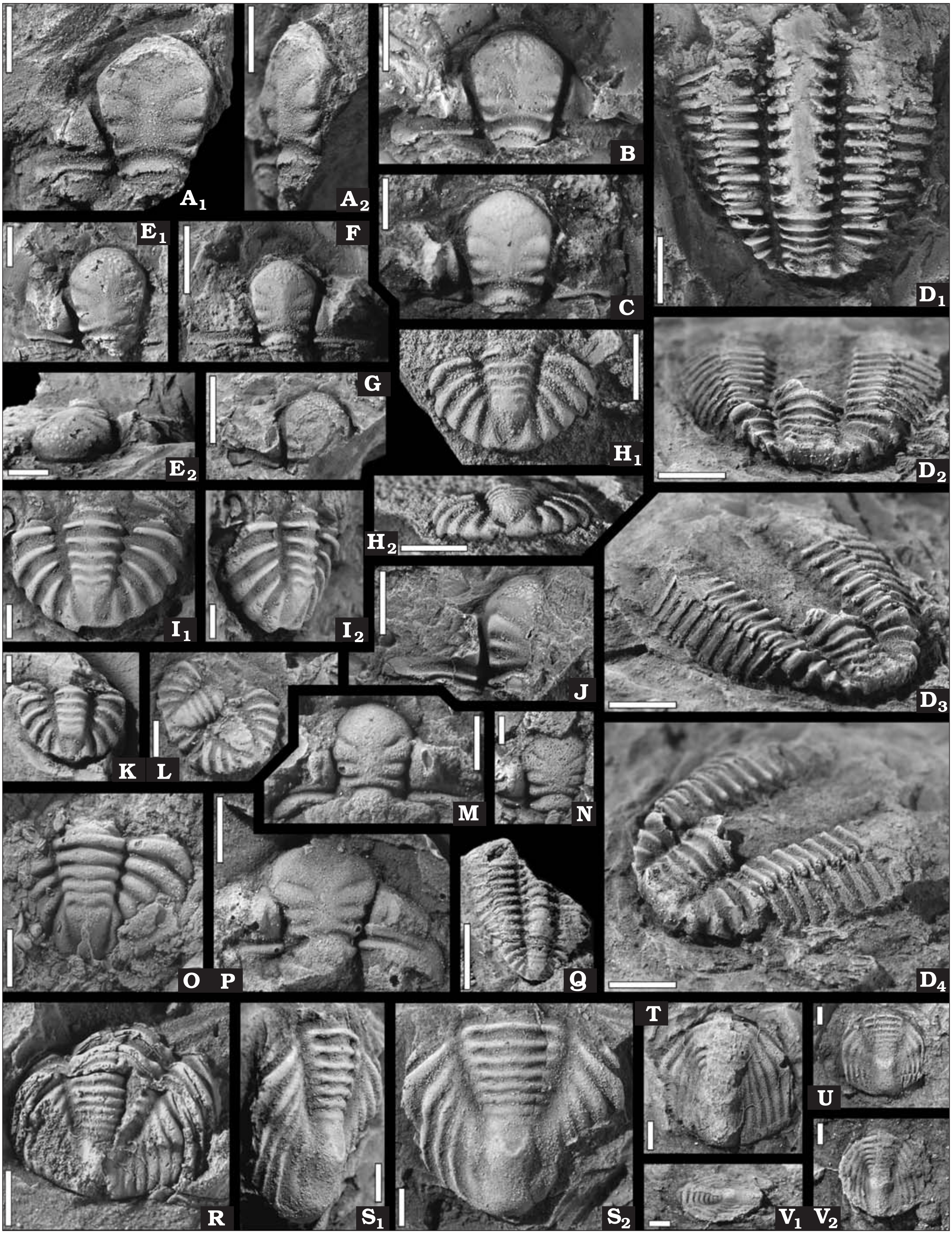
Genus *Neseuretinus* Dean, 1967

Type species: *Neseuretus* (*Neseuretinus*) *turcicus* Dean, 1967, from the Caradoc of Turkey; by original designation.

Neseuretinus? sp.

Fig. 11S–U.

Fig. 11. Late Ordovician trilobites from Xiazhen Formation near Zhuzhai, Yushan County, China. All specimens are collected from locality 3, except for NIGP-152079 (**R**) from locality 5. **A**–**L**, **O**, **Q**. *Pliomerina tashanensis* sp. nov. **A**. NIGP-152062, cranidium; dorsal (A_1) and lateral (A_2) views. **B**. NIGP-152063, holotype, cranidium, dorsal view. **C**. NIGP-152064, cranidium, dorsal view. **D**. NIGP-152065, thoraco-pygidium with nine thoracic segments (thoracic axis was inadvertently broken off while being photographed); dorsal (D_1), posterior (D_2), oblique left posterior (D_3), and oblique right posterior (D_4) views. **E**. NIGP-152066, cranidium; dorsal (E_1) and anterior (E_2) views. **F**. NIGP-152067, cranidium, dorsal view. **G**. NIGP-152068, cranidium, dorsal view. **H**. NIGP-152069, pygidium; dorsal (H_1) and posterior (H_2) views. **I**. NIGP-152070, pygidium; dorsal (I_1) and lateral (I_2) views. **J**. NIGP-152071, cranidium, dorsal view. **K**. NIGP-152072, pygidium, dorsal view. **L**. NIGP-152073, two pygidia, dorsal view. **O**. NIGP-152077, pygidium, cast of external mould, dorsal view. **Q**. NIGP-152074, thoraco-pygidium with nine thoracic segments, dorsal view; note that the presence of distal part of left posterior cranidial border, indicating that the number of thoracic segments is nine. **M**, **N**, **P**. *Pliomerina* sp. **M**. NIGP-152075, cranidium, cast of external mould, dorsal view. **N**. NIGP-152076, cranidium, cast of external mould, dorsal view. **P**. NIGP-152078, cranidium, cast of external mould, dorsal view. **R**. cf. *Reedocalymene* sp., NIGP-152079, pygidium with two thoracic segments, dorsal view. **S**–**U**. *Neseuretinus*? sp. **S**. NIGP-152080, pygidium; lateral (S_1) and dorsal (S_2) views. **T**. NIGP-152081, pygidium, dorsal view. **U**. NIGP-152082, pygidium, dorsal view. **V**. *Vietnamia* sp. D, NIGP-152083, pygidium; lateral (V_1) and dorsal (V_2) views. Scale bars 2.5 mm, except C, K–N, R–V 1 mm. →



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Material.—Four pygidia (repository numbers: NIGP-152080–152082).

Remarks.—These poorly preserved pygidia exhibit morphology similar to that of *Neseuretinus* (see Turvey 2005: pl. 2: 8) in sharing a sharply turning anterior margin and relatively distinct terminal piece. The rimmed nature of marginal border in some specimens (Fig. 11T, U) is unusual for reedocalymenines; *Reedocalymene* has the border that is rather flat than rimmed (see Peng et al. 2000: pl. 1: 1). No *Neseuretinus*-like cranidium with a pre-cranidial spine was found in the entire collection. It cannot be ruled out that the pygidium may be a dorso-ventrally compressed specimen of *Vietnamia* species (compare Figs. $8I_2$, $9D_1$, and $11S_1$). The assignment to *Neseuretinus* is uncertain.

Genus *Reedocalymene* Kobayashi, 1951

Type species: *Reedocalymene unicornis* (Reed, 1917), from the Middle Ordovician Shidian Formation of Yunnan, China.

cf. *Reedocalymene* sp.

Fig. 11R.

Material.—One pygidium (repository number NIGP-152079).

Discussion.—The pygidium is greatly similar to that of *Reedocalymene expansa* Yi, 1957 (see Peng et al. 2000: pl. 1: 1), but differs in lacking interpleural furrows posterior to cincture. Peng et al. (2000) noted the shorter (sag.) pygidial axis of *Calymenesun* (see Zhou et al. 1984: fig. 7e for *Calymenesun tingi* [Sun, 1931]) as the sole difference from pygidium of *Reedocalymene*. The pygidia of both genera have interpleural furrows in the pleural field posterior to cincture which are absent in this species. The absence of associable cranidial materials renders this species left in open nomenclature.

Family Cheiruridae Hawle and Corda, 1847

Genus *Ceraurinus* Barton, 1913

Type species: *Ceraurinus marginatus* Barton, 1913, probably from Upper Ordovician Cobourg Formation of Ontario, Canada (see Ludvigsen 1977).

Ceraurinus zhuzhaiensis sp. nov.

Figs. 3D, 10.

Etymology: After Zhuzhai village where the sampling quarries are located.

Holotype: NIGP-152016, articulated specimen from locality 2.

Type locality: Locality 2, about 60 m northwest of Zhuzhai, Yushan County. GPS coordinate is 28°34’23.27” N and 118°20’16.50” E.

Type horizon: Xiazhen Formation, Upper Ordovician, *Dicellograptus complexus* Graptolite Zone.

Material.—Three articulated exoskeletons, five cephalo-thoraces, four thoraco-pygidia, one cephalon, 12 cranidia, one thorax, one free cheek, and one hypostome (repository numbers: NIGP-152015–152028).

Diagnosis.—Species of *Ceraurinus* possessing three pairs of pygidial pleural ribs with free, blade-shaped antero-most pair and posterior two pairs expressed by smoothly saw-toothed pygidial margin, and pair of weakly-impressed pits on L4.

Description.—Dorsal exoskeleton elliptical in outline and covered with irregularly-distributed granules. Cephalon semi-circular in outline; transverse width 49% of sagittal length. Anterior cranidial border narrow, rimmed, and slightly indented sagittally. Anterior cranidial border furrow and preglabellar furrow merged, moderately impressed but shallower than axial furrow. Axial furrow deep and wide. Glabella sub-rectangular in outline, and slightly expands laterally or forwards in some specimens; maximum transverse width 86% of sagittal length. Central area of glabella moderately crested, which become more raised posteriorly, ending as if a large lobe is developed at posterior end; central area occupies 34% of maximum glabellar width. Three pairs of glabellar furrows present; S1, S2 and S3 equally spaced; S1 runs slightly obliquely backwards, then sharply turns posteriorly, and then merged with occipital furrow; S1 moderately deep and become shallower after turning posteriorly; S2 runs moderately obliquely and then sharply turns posteriorly, and moderately deep and become shallower after turning posteriorly; part of S2 which turns posteriorly much shallower than that of S1; S3 more obliquely directed backwards and become shallower to disappear adaxially; S3 longer than the obliquely-running part of S1 and S2. L1 and L2 sub-quadrate; pair of small pits present middle of L4. Occipital furrow curved forwards sagittally; adaxial two-thirds of the course much shallower than abaxial course. Palpebral lobe crescentic in outline and mid-point located opposite mid-point of L3; palpebral furrow moderately impressed. Preocular area of fixigenae very narrow (tr.) or nearly absent; palpebral area triangular in outline; postocular area sub-rectangular in outline, with relatively short spine at postero-lateral corner; fixigenal field covered with irregularly-dispersed pits. Posterior cranidial border straight, rimmed and obliquely directed forwards; posterior margin broadly indented at mid-length; posterior cranidial border furrow moderately deep, wide, and straight to slightly sinuous; articulating flange narrow and disappears adaxially. Anterior branch of facial suture gently curved forwards; posterior branch runs nearly transverse, and then gently turns posteriorly; facial suture of proparian type.

Librigena small, triangular in outline; librigenal lateral border furrow moderately impressed and merged with axial furrow opposite S1; librigenal field covered with irregularly-dispersed pits.

Hypostome shield-shaped. Anterior lobe of middle body sub-rectangular in outline; posterior lobe small and crescentic in outline. Anterior margin gently rounded; lateral margin strongly curved inwards at mid-point of anterior lobe, strongly projected outwards as shoulder, and then run obliquely straight backwards. Anterior border widens distally and narrows to be absent proximally; lateral border rimmed; lateral border furrows moderately deep and wide. Middle furrow shallow and disappears adaxially.

Thorax of 11 segments. Axis occupies 33% of thoracic width; axial furrow parallel-sided and then gently tapers backwards from the eighth or ninth thoracic segment. Axial ring slightly convex forwards sagittally and distal end curved forwards; axial ring furrow shallows adaxially with distinct elongated (tr.) apodemal pit at distal end. Pleura divided into anterior and posterior pleural band which are strongly convex and elongated triangular in shape, and separated from each other by deep, oblique pleural furrow; band width 37% of pleural transverse width; fulcral node moderately convex and subquadrate in outline. Anterior and posterior flange narrow, becoming narrower to disappear at half-way of pleura, and delineated by deep furrow. Pleural spine blade-shaped, and gently curved backwards distally; posterior spines progressively more strongly curved backwards; spine half as long as pleura.

Pygidium sub-elliptical in outline. Three axial rings and terminal piece present; axial ring curved forwards sagittally. Three pleural ribs present; first (from the anterior) pleural rib with pleural bands and fulcral node as in thoracic segments, distally ending with free, strongly curved, blade-shaped spine; second pleural rib with pleural bands but without distinct fulcral node; third rib lacks pleural bands and fulcral node. Lateral and posterior pygidial margin smoothly saw-toothed, corresponding the second and third pleural spines.

Discussion.—The genera of the subfamily Cheirurinae are distinguished from one another chiefly upon the basis of pygidial morphology (Ludvigsen 1977). Pygidial morphology of *Ceraurinus* is characterized by a pair of long, curved, carinated first pleural spines, and two pairs of relatively short posterior spines (see Ludvigsen 1977: text-fig. 1). The pygidium of *Ceraurinus zhuzhaiensis* sp. nov., however, has a non-carinated first spine and saw-toothed pleural margin corresponding the posterior two pleural spines (Fig. 10B$_1$, B$_3$, H, N). The carination of other *Ceraurinus* species is also observed in genal and thoracic pleural spines as well as pygidial pleural spines (see Ludvigsen 1977: pl. 1: 7 for *Ceraurinus marginatus* Barton, 1913), while *C. zhuzhaiensis* lacks the feature in any of these spines. In addition, *C. zhuzhaiensis* is characterized by having a pair of small pits on L4. A provisionally associated hypostome (Fig. 11F) has a shoulder that is narrower and located more posteriorly, and a border that is more narrowly rimmed, compared to those of other *Ceraurinus* species (see Ludvigsen 1977: text-fig. 3).

Following Ludvigsen's (1977) treatment of *Remipyga* as a junior synonym of *Ceraurinus*, Zhou and Zhen (2008: 242; misspelled as *C. sinensis*) transferred *Remipyga chinensis* Ju in Qiu et al. (1983) into *Ceraurinus*. It is the only *Ceraurinus* species listed in Zhou and Zhen, 2008 where other Chinese species previously assigned to *Ceraurinus* are transferred to other cheirurid genera. The sagittally-compressed, poorly-preserved cranidium (Qiu et al. 1983: pl. 81: 9) exhibits a comparable glabellar morphology of *Ceraurinus zhuzhaiensis* sp. nov., but it appears to be rather oval than sub-rectangular; the more poorly-preserved pygidium (Qiu et al. 1983: pl. 81: 10), which has three axial rings and first pleural rib with free blade-shaped spine, appears to have a much wider (tr.) pleural field posterior to the first pleura than *C. zhuzhaiensis*. Furthermore, *C. chinensis* occurs in the Wenchang Formation of the Hirnantian age, which is younger than the Xiazhen Formation.

Stratigraphic and geographic range.—Late Ordovician and Jiangxi Province, South China.

Family Encrinuridae Angelin, 1854

Genus *Erratencrinurus* Krueger, 1971

Type species: *Erratencrinurus capricornu* Krueger, 1971, from the Caradoc of Germany; by subsequent designation of Krueger (1972).

Erratencrinurus aff. *trippi* (Edgecombe, Banks, and Banks, 1999a)

Fig. 9K–M, O, P.

Material.—One thoraco-pygidium, three cranidia, three pygidia, one free cheek, and one thorax (repository numbers: NIGP-152057–152061).

Remarks.—This species resembles *Erratencrinurus trippi* Edgecombe, Banks, and Banks, 1999a (Edgecombe et al. 1999a: figs. 7A–E, G, H, 9I–L) from Tasmania. This species differs in having a straight fixigenal spine (directed moderately outwards in *E. trippi*) and less densely-distributed smaller tubercles on cranidium. In Zhou and Zhen (2008: 247) which summarizes trilobite records of China, listed is only a single occurrence of *Erratencrinurus*, which is from Inner Mongolia and has recently been described by Zhou and Zhou (2006). *Erratencrinurus* (*Erratencrinurus*) *ejinensis* Zhou and Zhou (2006: figs. 5E, G, I, J, M, 6A, D–F) differs from this species in having larger and more denser tubercles on cranidium; the cranidial tubercle formula of this species 1L-0, 2L-2, 1, 0, and 3L-3, 2, 1, 0, with large 3L-0 and that of *E.* (*E.*) *ejinensis* 1L-1, 2L-3, 2, 1, and 3L-3, 2, 1. The pygidia of *E.* (*E.*) *ejinensis* have 16 pleural ribs (see Zhou and Zhou 2006: fig. 6A, D-F), while those of this species have 11; the pygidia of both species lack tubercles on axial rings.

North American *Erratencrinurus* species differ in having much coarser tubercles on cranidium (see Lespérance and Desbiens 1995: figs. 3–14 for *Erratencrinurus spicatus* [Tripp, 1974]), and a sagittal tubercle on pygidial axial rings (see Lespérance and Tripp 1985: fig. 5f, i, j for *Erratencrinurus perceensis* [Cooper in Schuchert and Cooper, 1930]). This species would be a new *Erratencrinurus* species that is first recorded from South China region (see Zhou and Zhou 2006: 386 for geographic distribution of *Erratencrinurus* species), but better preserved material is needed to officially name it.

Family Pliomeridae Raymond, 1913

Genus *Pliomerina* Chugaeva, 1958

Type species: *Pliomera martelli* (Reed, 1917), from the Shihtien Formation (Llanvirn) of Pupiao, western Yunnan Province, China.

Pliomerina tashanensis sp. nov.

Figs. 3E, 11A–L, O, Q.

Etymology: After the Tashan village where the type section of the Xiazhen Formation is located.

Holotype: NIGP-152063, cranidium from locality 3.

Type locality: Locality 3, about 400 m southeast of Zhuzhai, Yushan County. GPS coordinate is 28°34'14.33" N and 118°20'22.41" E.

Type horizon: Xiazhen Formation, Upper Ordovician, *Dicellograptus complexus* Graptolite Zone.

Material.—Two thoraco-pygidia, nine cranidia, and eleven pygidia (repository numbers: NIGP-152062–152074, 152077).

Diagnosis.—Species of *Pliomerina* with abaxial end of S3 located posterior to antero-lateral glabellar corner, and more strongly backwardly curved posterior margin of pygidial axial rings.

Description.—Cranidium sub-triangular in outline. Anterior cranidial border narrow and rimmed; anterior cranidial border furrow moderately deep and concave; preglabellar field absent. Axial furrow deep and wide, steep-sided. Glabella elongated (sag.) pentagonal in outline; central area moderately carinated. Four pairs of glabellar furrows present; S1 elongated (tr.) triangular in outline and slightly curved backwards medially; S2 slit-like, straight, and transversely; S3 longest, obliquely directed posteriorly; adaxial end of S1/S2/S3 connected into shallow furrow to abaxially delineate carinated central area; abaxial end of S1/S2/S3 located within palpebral area of fixigenae; abaxial end of S3 posterior to antero-lateral glabellar corner; S4 weakly impressed, straight, obliquely directed, and isolated from axial furrow. L1 elongated (tr.) triangular in outline, protruded posteriorly to overhang occipital furrow, and distal end sharply curved forwards; L2 sub-rounded; L3 sub-triangular in outline and moderately convex; L4 paper fan-shaped in outline and covered with randomly-distributed tubercles while other lobes smooth. Palpebral lobe large, crescentic in outline, exsagittal length 41% of sagittal glabellar length, and posterior end overhangs posterior area of fixigenae. Palpebral furrow triangular in outline and shallow. Palpebral area of fixigenae narrow, elongated, and moderately carinated. Occipital furrow wide and gently curved forwards and shallows sagittally. Occipital ring spindle-shaped and distal end sharply curved forwards; occipital node weakly developed. Posterior cranidial border narrow and rimmed in adaxial two-thirds, and broad with rounded postero-lateral margin in abaxial one-third; posterior cranidial border furrow moderately deep and wide, becoming shallow to disappear distally. Postocular suture runs transverse and then sharply curved posteriorly.

More than 10 thoracic segments present. Axis slightly tapers backwards; axial ring narrows and curved forwards distally; axial furrow deep and wide. Pleura divided into adaxial and abaxial region by fulcral line; elongated (tr.) strongly raised ridge with slightly bulbous ends present in adaxial region; shallow furrow developed anterior and posterior to the ridge; abaxial region slightly obliquely directed backwards and diagonally divided into raised, flat band and depressed, flat articulating facet.

Pygidium semi-circular in outline. Axis gently tapers backwards with five axial rings and terminal piece; interring furrow moderately deep and become shallow and narrow adaxially, and gently curved backwards sagittally; terminal piece elongated (tr.) triangular in outline; postaxial ridge narrow (more distinct in internal moulds). Five pleural ribs present; each widens distally, and gently curved backwards and downwards distally; postero-most pair fused posteriorly and adaxially. Pleural furrow moderately deep and wide. Pygidial margin sawtooth-shaped due to distal projection of pleural ribs. No marginal border present.

Remarks.—*Pliomerina tashanensis* sp. nov. is most similar to *Pliomerina trisulcata* Edgecombe, Banks, and Banks, 1999a from Tasmania. However, *P. tashanensis* is readily distinguished by having the abaxial end of S3 located posterior to antero-lateral glabellar corner. Other species including *P. trisulcata* have the end anterior to the corner; see *P. trisulcata* Edgecombe et al. (1999a: fig. 10D), *Pliomerina peripata* Edgecombe et al. (1999b: figs. 1.1–1.5) from Argentina, *Pliomerina martelli* (Reed, 1917) (see Sheng 1974: pl. 7: 5a–c) from Yunnan, and *Pliomerina serrata* Zhou and Zhou (2006: fig. 4A, B) from Inner Mongolia. Posterior margins of pygidial axial rings of *P. tashanensis* are more strongly curved backwards (see Fig. 11O for cast of external mould), compared with *P. trisulcata* (see Edgecombe et al. 1999a: fig. 9F). Other species have a straight posterior margin; for example, see *Pliomerina austrina* Webby (1971: pl. 114: 8), *P. peripata* Edgecombe et al. (1999b: figs. 1.15–1.18).

Stratigraphic and geographic range.—Late Ordovician and Jiangxi Province, South China.

Pliomerina sp.

Fig. 11M, N, P.

Material.—Three cranidia (repository numbers: NIGP-152075, 152076, 152078).

Remarks.—From co-occurring *Pliomerina tashanensis* sp. nov., this species is discriminated by having the abaxial end of S3 at antero-lateral glabellar corner, shorter (sag.) glabella, and non-carinated palpebral area of fixigenae. Of *Pliomerina* species: *P. austrina* Webby, 1971 and *P. prima* Webby, 1971 from New South Wales, Australia; *P. dulanensis* Chugaeva, 1958 from Kazakhstan; *P. serrata* Zhou and Zhou, 2006 and *P. rigida* Kolobova, 1972 from Inner Mongolia exhibits comparable cranidial architecture. The cranidia however differ in having a more rounded anterior margin, less deeply impressed glabellar furrows, larger palpebral lobe that is located more posteriorly, and longer (tr.) posterior border.

Discussion

Characteristics of the fauna.—The trilobite fauna from the mudstone beds of the Xiazhen Formation comprises 25 species, 14 genera, and ten families (Table 1). Of these, five species are new: *Remopleurides xiazhenensis* sp. nov., *Hibbertia aodiensis* sp. nov., *Vietnamia yushanensis* sp. nov., *Ceraurinus zhuzhaiensis* sp. nov., and *Pliomerina tashanensis* sp. nov. These new species represent about 70% of the specimens collected; other species, which are all described in open nomenclature, each represent 1.7% in average. Of the ten families, six belong to those of Whiterock fauna and four to those of Ibex fauna (Adrain et al. 1998, 2004); those belonging to the Whiterock fauna families account for 71% of the total specimens.

Zhou et al. (2004: fig. 2.5.1) recognised three trilobite associations during the mid-Ashgill of South China, and the *Pliomerina–Vietnamia* association is recognized in carbonate buildups in Changshan area which includes the Zhuzhai area. Although the fauna from the Xiazhen Formation consisting of ten genera of nine families was mentioned, the recognition is mainly based on the trilobite assemblages from Huishandi and Jitoushan section of the Sanqushan Formation (see Zhan and Cocks 1998: text-fig. 1 for location of the sections); the fauna has not received a proper systematic treatment either. *Pliomerina* (56%) and *Vietnamia* (20%) are said to be the major components of the assemblage, so that the association is named after these two genera. Unlike the Sanqushan fauna associated with carbonate mudmounds, the Xiazhen fauna associated with mudstone is predominated by *Vietnamia* (39%); *Pliomerina* accounts for only 13% (see Table 1). The difference from the Sanqushan fauna can be attributed to a lateral biofacies change in relation to co-existing sedimentary facies in a rimmed shelf setting (Li et al. 2004: fig. 12).

Seventy five percent of the specimens are assigned to the four phacopid families (Table 1); the Calymenidae (43%; all belongs to the subfamily Reedocalymeninae), Cheiruridae (14%), Pliomeridae (13%), and Encrinuridae (5%). These phacopids seem to be rare in other Ordovician biogeographical areas of China than South China region (see Zhou and Zhen 2008: figs. 1–4) for the Ordovician palaeogeographical units of China). In Zhou and Zhen (2008) which has summarised trilobite records of China, listed are two occurrences of *Vietnamia* from Xinjiang and Xizang (Tibet) (Zhou and Zhen 2008: 241), a single occurrence of *Erratencrinurus* from Inner Mongolia (Zhou and Zhen 2008: 247; this has been described by Zhou and Zhou 2006), and no occurrence of *Ceraurinus*. *Pliomerina*, the third dominant taxon of the Xiazhen fauna, occur in nearly all biogeographical units of China; a total of nine occurrences are listed (Zhou and Zhen 2008: 263).

Outside China, *Vietnamia* has been reported from Sardinia, Vietnam, Himalayas, Tasmania, Uzbekistan and Tadzhikistan (Turvey 2005 and see references therein); *Ceraurinus* from North America (Ludvigsen 1977 and see references therein) and Kazakhstan (Chugaeva 1958); *Pliomerina* from South Korea, Kazakhstan, Turkey, Australia (New South Wales and Tasmania), and Argentina (Zhou and Zhou 2006 and see references therein); and *Erratencrinurus* from England, Norway, Germany, Estonia, North America and Tasmania (Zhou and Zhou 2006 and see references therein). There is no region where all four genera occur together. *Vietnamia*, *Pliomerina*, and *Erratencrinurus* occur together in Tasmania (Edgecombe et al. 1999a), which is the sole occurrence of *Vietnamia* with other taxa; *Vietnamia*, however, appears to be a minor component in this fauna. *Ceraurinus* and *Erratencrinurus* occur together in North America and *Ceraurinus* and *Pliomerina* in Kazakhstan. This indicates that the phacopid-dominant Xiazhen mudstone fauna is unique during the Late Ordovician, even in the global scale. The fact that the major elements of the fauna are new to science further supports that the faunal affinity to any biogeographical regions cannot be inferred. It seems that the association of the fauna with a localized reef system, probably within an isolated platform in South China Plate (Zhang et al. 2007: figs. 2–21) is the reason for this faunal uniqueness.

Stratigraphical implication of trilobite occurrences.—Comparison of the trilobite occurrences in present study with the previous occurrence data bears an interesting implication for stratigraphy of the Xiazhen Formation (Table 2); the mudstone strata of locality 2 in this study correspond to those of stratigraphical unit 7 in Chen et al. (1987: fig. 1; see also Zhang et al. 2007: figs. 4–2), those of locality 3 to unit 11, and those of locality 4 and 5 both to unit 18. The mudstone strata of locality 1 are not recognized in the stratigraphical column by Chen et al. (1987: fig. 1). Considering the average dip angle of 19° SE and the trilobite composition (Table 1), the mudstone strata of locality 1 are considered to be contemporaneous with those at locality 2. The mudstone strata of locality 4 are contemporaneous with those of locality 5, since the same trilobite fauna occur in both localities. The trilobite composition of locality 3 is unique in that *Pliomerina* and *Meitanillaenus*, the dominant elements do not occur in other localities (see Table 1). This indicates that the mudstone layers at locality 3 are a stratigraphically different unit from those at other localities.

The stratigraphical column by Zhang et al. (2007: figs. 4–2) shows that the Xiazhen Formation exposed at Zhuzhai is conformable across three exposures in Fig. 1, with the one at northwest being oldest. This suggests that the mudstone at locality 4 and 5 is stratigraphically younger than that at locality 1 and 2, with that at locality 3 being placed in the middle; the localities 1 and 2 and localities 4 and 5 are separated more than 200 m apart in vertical thickness. However, the trilobite assemblages from localities 1, 2, 4, and 5 are greatly similar to each other (Table 1), indicating that the mudstone strata of these localities are likely to be stratigraphically contemporaneous. Other fossils including brachiopods, cephalopods, and crinoids also show a similar occurrence pattern (see Table 2 for brachiopod occurrence). Such repeated occurrence of the identical trilobite assemblage along the dip direction suggests that the outcrops of the Xiazhen Formation are overlapped. This may be due to structural movement caused by large-scale tectonic movements of South China Plate and Cathaysian Land (e.g., see Guo et al. 2009 and references therein). Alternatively, but less likely, the same fauna comprising benthic mobile, sessile, and nektonic animals might have re-colonized the environment where the mudstone at Locality 4/5 was deposited; the repeated occurrence of the same brachiopod assemblages was interpreted to represent oscillation of the assemblages along palaeo-shoreline throughout deposition of the Xiazhen Formation by Zhan et al. (2002: see fig. 11).

Conclusions

A newly described trilobite fauna from the mudstone beds of the Upper Ordovician Xiazhen Formation includes five new species and 20 species in open nomenclature. The fauna predominated by phacopids appears to have inhabited the muddy substrate after decimation of the reef system. The fauna is unique among the Late Ordovician trilobite fauna, most of which are not associated with reef and not dominated by the phacopids.

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