Detailed trilobite biostratigraphy across the proposed GSSP for Stage 5 (“Middle Cambrian” boundary) at the Wuliu-Zengjiayan section, Guizhou, China

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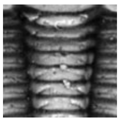

Quarrying across a potential GSSP of the base of Cambrian Stage 5/Series 3 at the Wuliu-Zengjianyan section in south China indicates a significant change in trilobite and brachiopod faunas. The Wuliu Quarry spans approximately 4.5 m across the potential boundary, which is the FAD of *Oryctocephalus indicus* (Reed, 1910) in the Wuliu-Zengjiayan section of the Kaili Formation. Trilobite taxa found consist of one *Pagetia*, one *Redlichia*, one *Burlingia*, two *Olenoides*, eleven oryctocephalid, and seven ptychopariid species. Non-trilobite taxa found in the Wuliu Quarry, but not described in this publication, include tubular shells, inarticulate and articulate brachiopods, molluscs, echinoderm plates, sponges, algae, acritarchs, and trace fossils. Collected specimens display both flattening, secondary calcite preservation, and tectonic distortion. Many of the species have previously been based on length to width ratios. Given the range of morphologies demonstrated in these collections, several previously named species have been synonymized. Detailed collections from the Wuliu Quarry show that the faunas of the *Ovatoryctocara* cf. *granulata-Bathyonotus holopygus* and the *O. indicus* zones changed in a 20 cm, relatively barren interval. This faunal turnover does not coincide with a lithologic change and suggests that the section would be a good location for the GSSP of the base of Cambrian Stage 5/Series 3.
• Key words: Cambrian, trilobites, Kaili Formation, South China.

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The lower boundary of Stage 5 of the Cambrian has yet to be determined. Recent work (Sundberg 2009, McCollum & Sundberg 2010) by the “Lower-Middle” Cambrian Boundary Working Group has narrowed down the biohorizon possibilities that should be considered for defining this boundary. The first candidate is the first appearance datum (FAD) of *Oryctocephalus indicus* (Reed, 1910), the second candidate is the FAD of *Ovatoryctocara granulata* Tchernysheva, 1962. A potential GSSP for this boundary using *O. indicus* has been proposed by Zhao *et al.* (2005a, see for further references) and is located at the Wuliu-Zengjiayan section near Balang, Guizhou Province, China (Fig. 1).

This paper reports on the trilobites of a quarry excavated next to the proposed GSSP at the Wuliu-Zengjiayan section (Fig. 2). This quarry is here referred to as the “Wuliu Quarry”. The intent of this study is to provide detailed stratigraphic and biostratigraphic information for approximately 4.5 m of section that transects the FAD of *O. indicus*. A preliminary report on this quarry was published by Sundberg *et al.* (2010b). This report contained a stratigraphic range chart (Sundberg *et al.* 2010b, fig. 1); however some taxonomic nomenclature has been changed. These changes are mentioned below in the systematic section.

The general depositional environment of the Kaili Formation has been discussed by Zhou *et al*. (1980), Zhao *et al*. (1994a), Zhang *et al*. (1996), Zhu *et al*. (1999) and Lin (2008, 2009). The Kaili Formation occurs in the Jiangnan Slope Belt between the shallow water Yangtze Platform and the deeper water Jiangnan Basin (Lu *et al*. 1974b; Zhou *et al*. 1980; Zhao 1990; Zhang *et al*. 1996; Yuan *et al*. 2002; Lin 2008, 2009). The claystones of the Kaili Formation have an absence of siliciclastic silt and sand, common mm scale lamina and common layers of concentrated trilobite

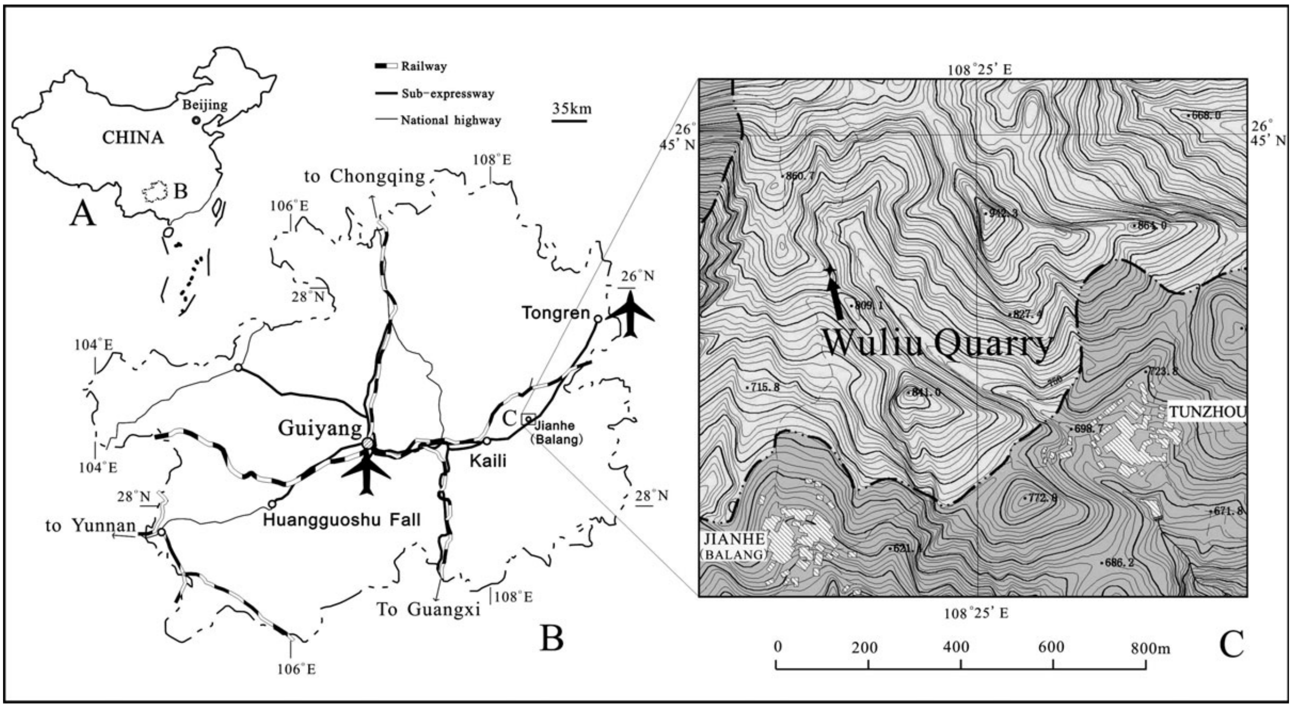


Figure 1. A – map of China showing the Guizhou Province. • B – map of the Guizhou Province, China, showing the position of the Wuliu-Zengjiayan section. • C – topographic map showing the precise location of the Wuliu Quarry at the location of the potential GSSP in the Wuliu-Zengjiayan section, modified from 1:10,000 scale topographic map G-49-37-47 of the Wuhe Area (Surveying and Mapping Bureaus of Guizhou and Shanxi provinces 1990).

sclerites suggest that the sediments were deposited below storm-wave base by turbid suspension gravity flows (Gaines *et al.* in press), but probably within the lower limit of the photic zone based on potentially *in situ* algal flora (Lin 2009). The presence of truncation surfaces and small scale slumping next to or in the Wuliu Quarry (Fig. 3) suggests failure close to the sediment water interface (Gaines 2011, personal communication), indicating a paleoslope. The Kaili Formation is inturpeted to be a 3rd order cycle with the maximum flooding surface located at or near the FAD of *O. indicus* (Wang *et al.* 2006, Lin 2009, Gaines *et al.* in press). In addition, a negative carbon isotopic excursion occurs within 4 m below the FAD of *O. indicus* (Yang *et al.* 2003; Guo *et al.* 2005, 2010; Lin 2009, 2010, 2011).

Methods

Wuliu Quarry. – The quarry (Figs 2, 4) was selected adjacent to the proposed GSSP at the Wuliu-Zengjiayan section, near the town of Balang, Jianhe County, Guizhou Province, China (26° 44.846´ N, 108° 24.830´ E, elevation 803 ± 11 m; UTM N 242789.9, E 2961075.3, Zone 49; Fig. 1). The upper third of the quarry was 1.2 m below the 56 m mark of the proposed GSSP section and less than 1 m away. The lower two thirds of the quarry were moved 2 to 3 m away from the proposed section to insure that no damage was done to the established section.

Excavation of the quarry involved the removal of layers (levels) of strata in approximately 0.25 to 0.5 m^2 to a depth of 10 cm (10.0 ± 2.1 cm). Based on the measured width, length and depth of each level, the volume of rock excavated for each level averaged 0.036 ± 0.014 m^3 (Fig. 5). The total volume of rock excavated was approximately 1.6 m^3. Levels of strata were removed parallel to their dip that ranged from 12° to 21°. The base of each level was excavated along bedding planes, but some levels produced irregular bottoms due to fractures and/or poorly splitting layers. The most irregular surfaces were in the middle portion of the quarry (levels FZX11–30, Figs 4, 5).

Stratigraphic logging was done after the quarry was finished. The total depth excavated was 452 cm, which was determined by adding individual level depths together. Correcting for the dip, the total depth was 434 cm, a 5.3% difference. Once the quarrying was finished, the location of each level marker was done again, correcting for the additive errors resulting from the individual level measurements and stratigraphic dip. This measurement indicated a stratigraphic thickness of 428 cm, which is only a 1.4% difference from the calculated thickness corrected for dip.

Bulk material from each level was kept separate and placed on plastic sheets to avoid mixing during the search for specimens. Once the specimens were collected, the material was trimmed down and wrapped in newspaper labeled with the level number.

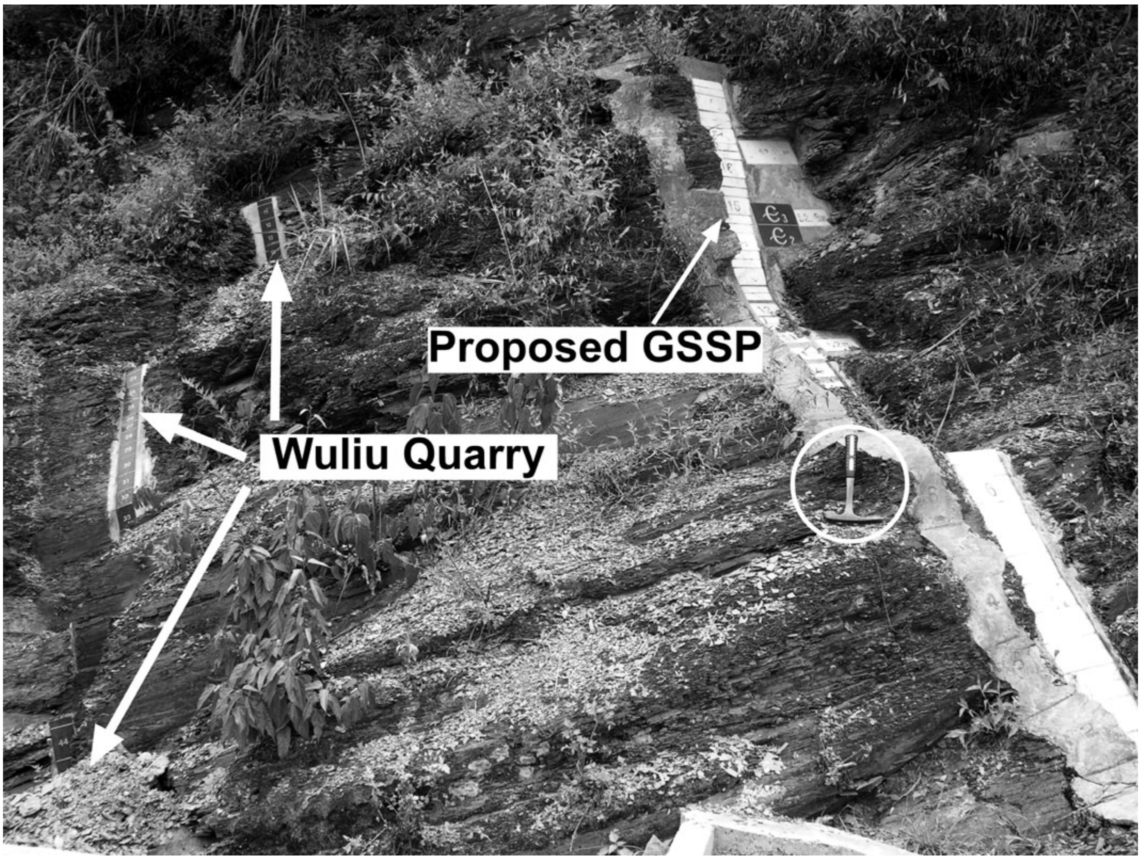


Figure 2. Outcrop photograph of the proposed GSSP for the Cambrian Stage 5 in the Wuliu-Zengjiayan section (white marble markers, arrow points to the proposed GSSP) and the Wuliu Quarry studied in this paper (black gabbro markers). The top of the Wuliu Quarry is not visible in photograph, but is located nearly a metre from the proposed GSSP section. Rock hammer (circled) for scale. Photograph by Yuning Yang.

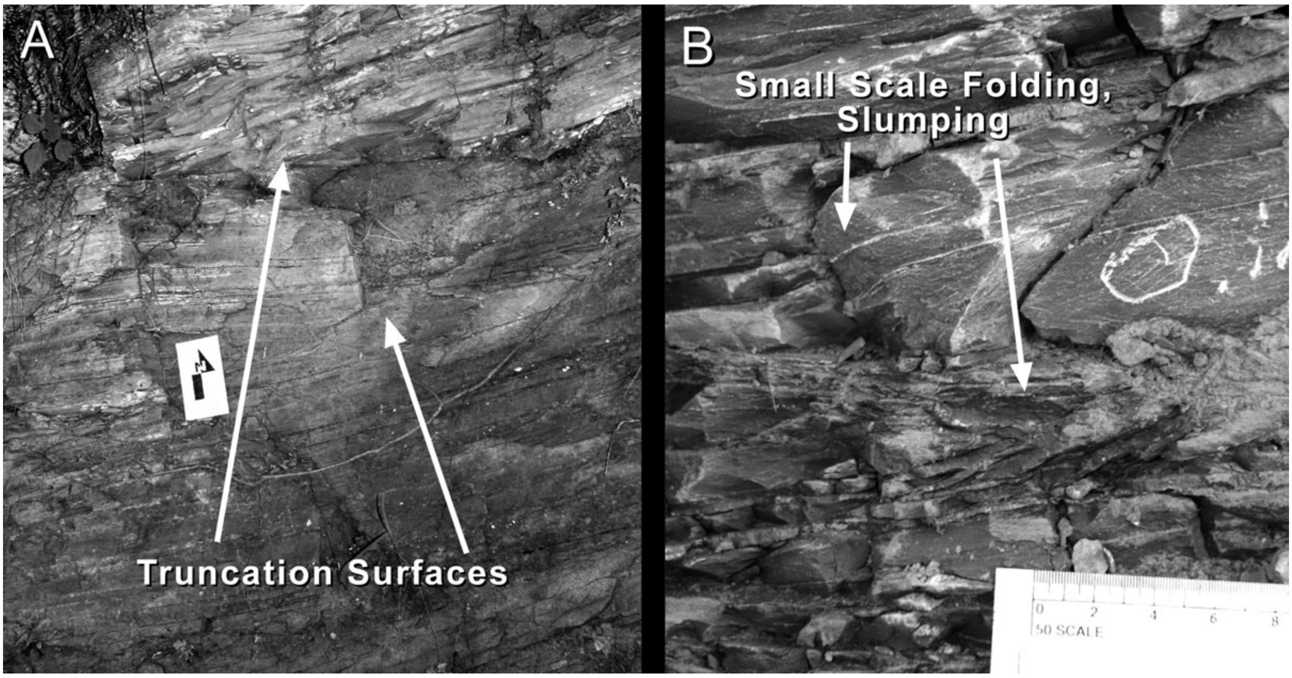


Figure 3. Sedimentary features indicating a depositional paleoslope of the Kaili Formation near and in the Wuliu Quarry. • A – outcrop exposure of truncation surfaces in the mudstones. • B – small scale folding indicating slumping.

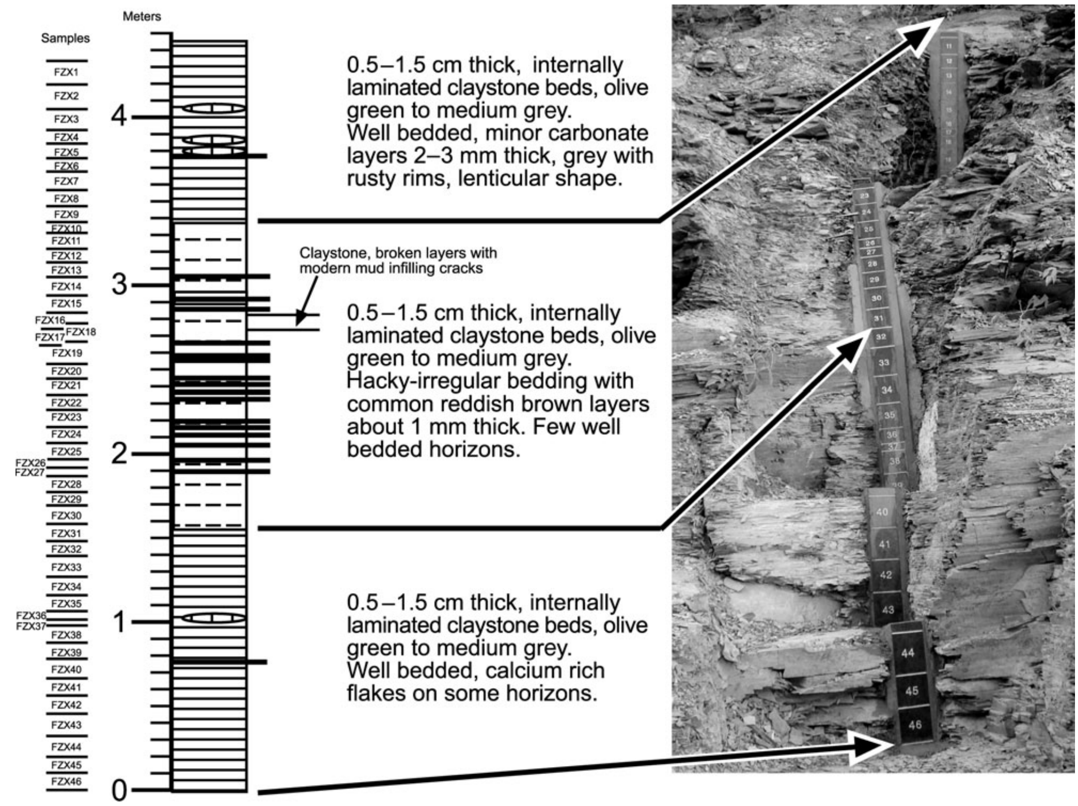


Figure 4. Stratigraphic profile of the Wuliu Quarry showing the levels and lithologies. The photograph illustrates the bottom portion of the quarry showing the boundary between the lower laminated claystones and the middle irregularly bedded mudstones. Grey bars of excavation volumes inticate the total volume excavated for FZX18, which overlapped the levels FXZ16 and 17 due to the moving of the quarry outwards; FZX26+27 inticates the total additional volume of the 10 cm level collected in detail below the FAD of *O. indicus*; and FZX36+37 indicates the total volume of the 10 cm level that was broken into two intervals due to a limestone layer (FZX37). Photograph of quarry by Tongshu Tai.

Trilobite identifications. – Identification of the ptychopariid trilobites and to a lesser extent the other trilobites was complicated primarily as the result of: 1) tectonic distortion; 2) compaction; 3) glabella similarity of several genera; 4) the lack of pygidium for generic identification; 5) over splitting of species/genera based on distorted specimens; and 6) specimens missing or having calcite replaced exoskeletons. Large collections of specimens of a species were needed to determine the effects of distortion. The figured specimens illustrate the range of distortions and ontogenetic stages. Several features were used for identification, but the comparison of width vs. length ratios were avoided because these features are strongly affected by tectonic distortion (Fig. 6). Features such as the length (sag., exsag.) of the glabella, cranidium, palpebral lobes, posterior area of the fixigena, preglabellar field, and anterior border were commonly compared. Widths (tr.) of the fixigena, glabella, posterior area of the fixigena, and anterior and posterior glabellar were also compared. Pygidial features include the length and width of the axis relative to the entire pygidium, number of axial rings, depth of pleural/interpleural furrows, marginal border, and relative changes in the doublure from the anterior to the posterior margin.

Due to tectonic and compressional distortion of the specimens from the Wuliu Quarry and Wuliu-Zengjiayan section in general, emended diagnoses for the taxa are also presented to provide a guide for the criteria used to identify the different species. Suggested synonymies are presented below; but without a detailed taxonomic/taphonomic study of each species, these synonymies are still questionable. Specimens from the nearby Miaobangpo section (Yuan *et al.* 2002) appear to be less distorted and would be a better database for a taxonomic revision. A detailed morphometric study is out of the scope of this paper.

Abundance. – The minimum numbers of individuals are illustrated in Figs 5 and 7. All late meraspids and holaspides of each species were counted. The identification of late meraspids were based on having growth sequences of several of the taxa and that only one species of *Pagetia* Walcott, 1916, was identified. Specimens were recorded as cranidia or pygidia, either positives or negatives. Over 15,000 cranidia and pygidia were counted, however the minimum number of individuals is based on the highest count of either positive *or* negative of either cranidia *or* pygidia for each species for each excavated level. For example, if 20

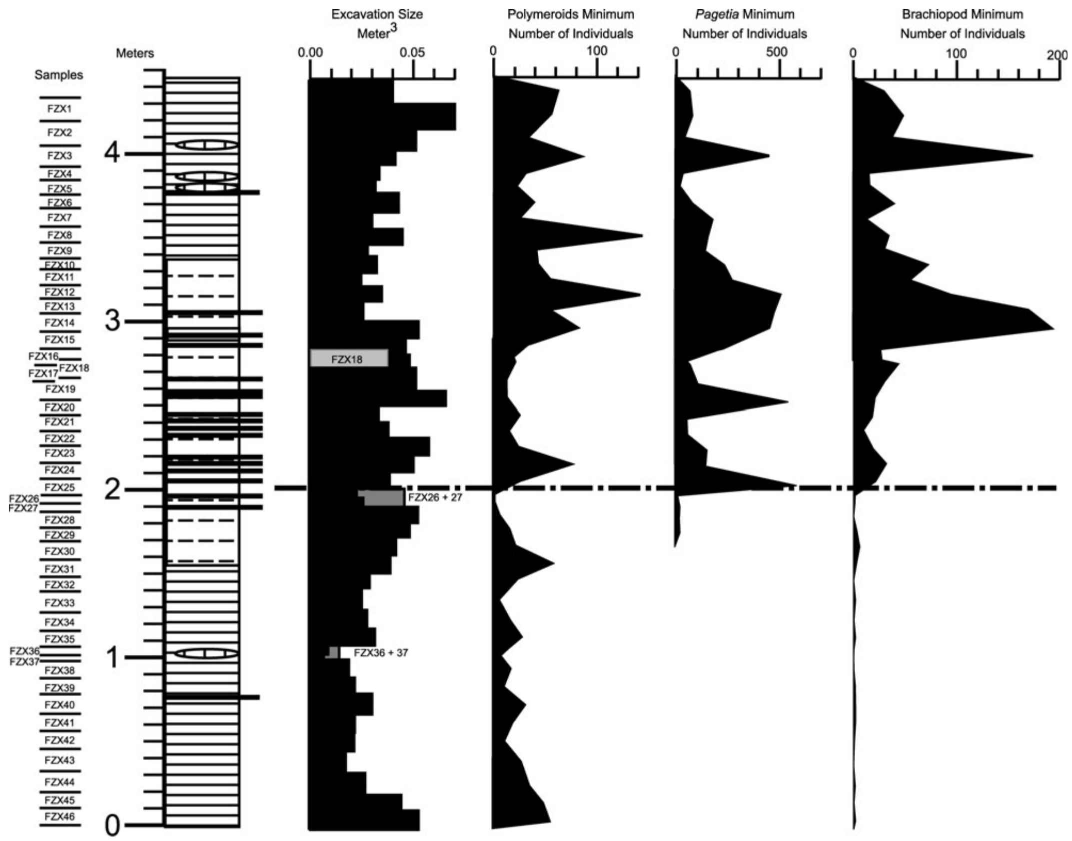


Figure 5. Stratigraphic profile of the Wuliu Quarry illustrating the amount of rock excavated from each level and the minimum number of individual or polymeroid trilobites, *Pagetia taijiangensis* Yuan & Zhao *in* Yuan *et al.*, 1997, and brachiopods (the sum of the abundant inarticulate and the rarer articulate brachiopods). Dashed line is the FAD of *Oryctocephalus indicus*. Note that the *Pagetia* count scale is five times greater than the other count scales.

positive cranidia, 13 negative cranidia, 7 positive pygidia, and 10 negative pygidia of a particular species were from a particular excavated level, the minimum number of individuals for that species for that level is 20. Occasionally other sclerites were used to document the number of specimens if the species did not have either cranidia or pygidia present in a level. Specimens of questionable taxonomic assignment were assigned to the closest and/or most abundant species in the surrounding levels. Levels that contain only questionably assigned species are marked with a question mark next to the abundance curves.

The minimum number of individuals differs from the total number of specimens listed under Materials in the systematic section. This number is the sum of each level's maximum number of cranidia (positive or negative), pygidia (positive or negative), and partial or complete shields (positive or negative) for the entire quarry. Using the example given above, this would give a total of 20 cranidia and 10 pygidia for a particular species from a particular excavated level; a total of 30 specimens from that level, not the minimum number of individuals of 20 as given above.

Brachiopods were counted as either positives or negatives. No distinction was made between brachial and pedicle valves due to the difficulty of identifying the differences between the two valves given the molds and casts and poor preservation of some of the material. Because of the lack of distinction between the two valves, abundances of brachiopods were divided in half to provide a minimum number of individuals.

Results

Lithology. – The Wuliu Quarry section is predominately composed of olive-green to medium-grey claystone (Fig. 4). The stratigraphic package is divided into three units. The upper and lower units are well-bedded claystones with 5 to 15 mm thick beds, internally laminated. The lower unit is 1.55 m thick and contains several secondary calcite flakes and layers. One 5 cm thick micrite nodule occurs at about 1 m from the bottom of the section. The upper unit is 1.1 m thick with minor lenticular carbonate layers 2 to 3 mm thick, grey in color with rust colored rims (altered pyrite; Gaines *et al*. in press).

The middle unit, which contains the FAD of *O. indicus*, is 1.8 m thick and composed of irregular bedded claystones with few well-bedded horizons. Beds range from 5 to

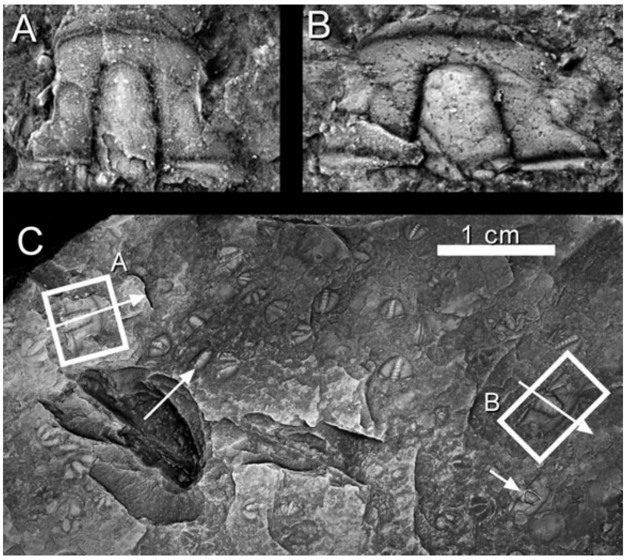


Figure 6. Claystone sample with tectonically distorted specimens of *Xingrenaspis xingrenensis* Yuan & Zhou *in* Zhang *et al.*, 1980, and *Pagetia taijiangensis* Yuan & Zhao *in* Yuan *et al.*, 1997, FZX23. • A – sagittally elongated, partially exfoliated cranidium of *Xingrenaspis xingrenensis*, × 6, GK B3 0001. • B – transversely elongated, exfoliated cranidium of *Xingrenaspis xingrenensis*, × 6, GK B3 0002. • C – claystone slab showing the nearly 90° orientation of specimen A and B (boxes); arrows point anteriorly, the adjacent cranidia marked with arrows only show the same morphology, × 1.6.

15 mm in thickness with internal lamination. Coarser layers are common throughout this unit. These units are typically rusty colored and are the result of altered pyrite (Gaines *et al*. in press). Many of these layers contain molds and casts of trilobite sclerites suggesting that the carbonate has been dissolved.

Preservation. – Trilobite specimens within the quarry are preserved as isolated specimens or in the current concentrated deposits. Most specimens are disarticulated, although articulated or partially articulated specimens are found in both the claystones and in the current concentrated layers. Specimen size ranges from small meraspids (~1 mm) to 1 cm or larger in nearly all horizons. Almost all specimens are molds and casts, few have exoskeletons preserved. Calcite layers separating the mold and cast are common. This calcite is clearly secondary because of the extension of the material into the surrounding bedding plane and its crystalline appearance (also see Zhu *et al*. 1999).

Trilobite specimens are commonly compressed and cracked due to compaction of the sediments and tectonically distorted. Shear planes cutting through the section and tectonic lineation further document the distortion of the specimens.

Taxonomic distributions. – A total of one *Pagetia*, two *Olenoides* Meek, 1877, one *Redlichia* Cossmann, 1902, eleven oryctocephalid, and seven ptychopariid species were identified from the quarry. The total of 22 trilobite species is less than previously reported (see discussion below) as a result of the more conservative taxonomic approach due to preservation. Only one species of articulate brachiopod and one of inarticulate brachiopod were identified from the quarry.

Detailed collecting throughout the quarry shows considerable variation in the minimum number of individuals found in each level (Fig. 5). The polymeroids average 22 ± 17 minimum number of individuals per excavated level. Correcting for average volume of each excavated level, the average density of the polymeroid minimum number of individuals is about 625 individuals per cubic meter. In contrast, specimens of *Pagetia taijiangensis* Yuan & Zhao *in* Yuan *et al.*, 1997, are much more abundant when they occur (FZX1–29). The average minimum number of *Pagetia* individuals in these levels is 145 ± 192 (skewed distribution produces a large variance) and about 4000 individuals per cubic meter. Brachiopod minimum number of individuals differs below and above the FAD of *O. indicus*. Below the FAD, *Eoconcha* sp. (Leonid Popov 2010, personal communication; = *Nisusia* sp. *in* Huang *et al.* 1994) averages 2 ± 1 individuals in each excavated level were they occur. Above the FAD, *Linnarssonia* cf. *constans* Koneva *in* Gorjansky & Koneva, 1983 (Leonid Popov 2010, personal communication = *L. agyrekensis* Koneva, 1979 of Huang *et al.* 1994) are more abundant, with the minimum number of individuals averaging 19 ± 13 per excavated level.

There are several levels that have very low specimen counts; the most significant are FZX26 to 28 where very few fossil specimens are found despite additional collections made from these levels (Fig. 5, FZX26+27, grey rectangle). This relatively barren zone is 20.5 cm thick within the middle unit of the lithologic section, but does not mark a distinct change in lithology. This barren zone, however, marks the boundary between two distinct assemblages that represent the *Ovatoryctocara* cf. *granulata-Baythyonotus holopygus* Zone and the overlying *Oryctocephalus indicus* Zone (see below).

Non-trilobite fossils found in the Wuliu Quarry, but not discussed further in this publication, range from very rare to abundant. Sponges are represented by rare isolated spicules of *Chancelloria* (FZX39, 46) and *Choia* (FZX39). The brachiopods are *Linnarssonia* cf. *constans* (FZX1–25, 29–31) and *Eoconcha* (FZX3, 9, 15, 30, 31, 33, 35, 39–41, 44, 46). The tubular shelly fossil is represented by *Cambrovitus balangensis* Mao *et al.*, 1992 (FZX32, 34, 35, 39, 40). The molluscs are *Scenella radians* Babcock & Robison, 1988 (= *Scenella taijiangensis* Huang & Dai, 1998) (FZX16, 31, 34, 41, 43, 45, 46); *Helcionella terraustralis* Runnegar & Jell, 1976 in Mao *et al.* (1993) (FZX9, 12, 14); *Latouchella taijiangensis* Mao *et al.*, 1993 (FZX5, 13, 14); an unidentified hyolithid (FZX1, 4, 8, 9,

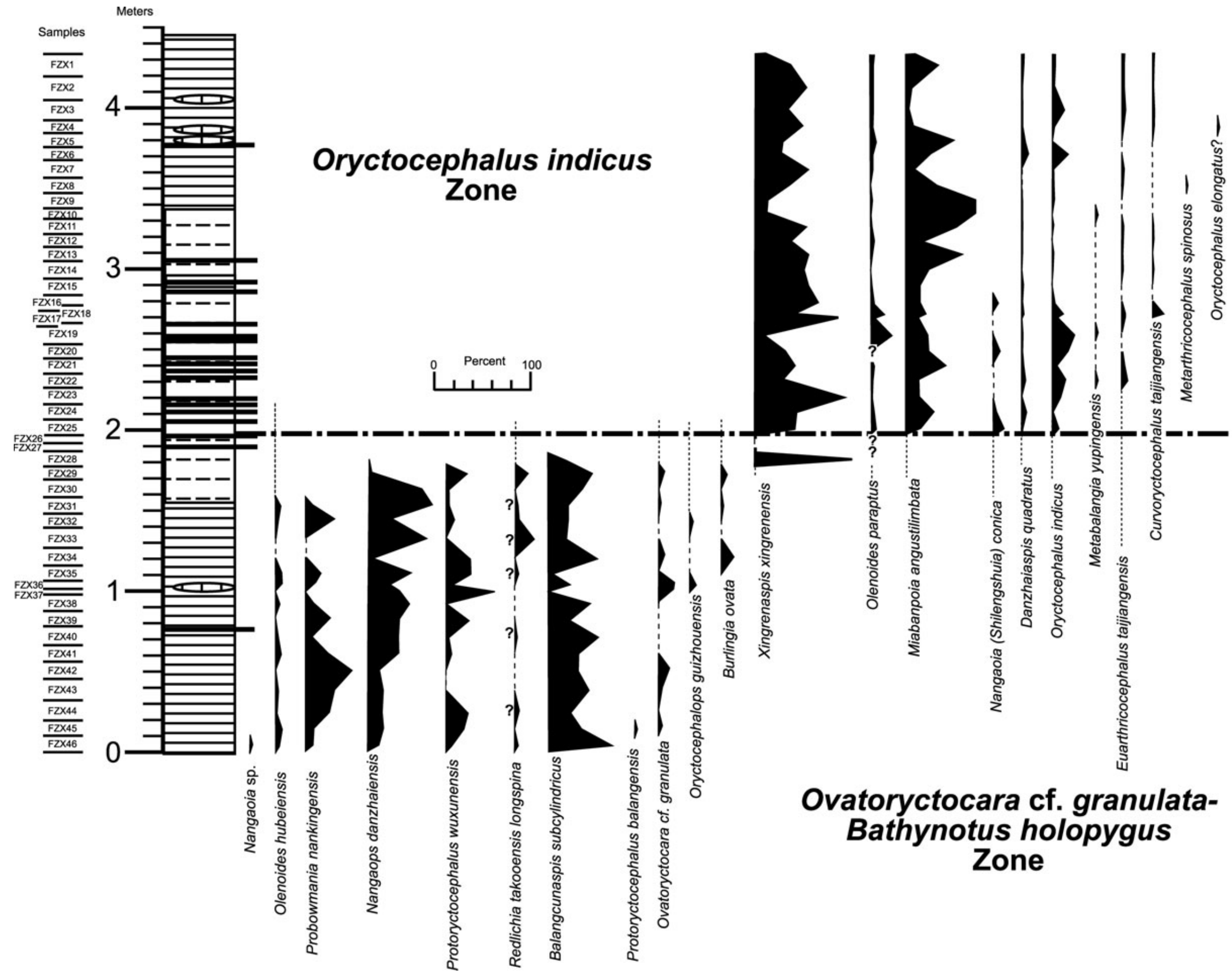


Figure 7. Distribution of the polymeroid trilobites and their relative abundances for each level in the Wuliu Quarry. Relative abundance based on minimal number of individuals and exclusive of *Pagetia* and brachiopods. The thin dashed lines at the top or bottom of taxa ranges indicate potential range extentions of taxa near the FAD of *O. indicus*. See text for discussion.

12, 14, 16, 23, 29, 33); and isolated sclerites of *Wiwaxia taijiangensis* Zhao *et al*., 1994b (FZX2, 7, 14, 15, 18–20, 24, 32, 39, 43, 45). Isolated echinoderm plates probably represent eocrinoids (FZX1, 6–12, 14, 15, 21, 25). The algae are *Bosworthia simulans* Walcott, 1919, in Mao *et al.* (1994) (FZX42, 45, 46). The trace fossils are dominated by *Trichophycus pedum* (Seilacher, 1955) in Lin *et al.* (2010) (FZX2, 5, 10, 11, 20, 21). The acritarchs from the Kaili Formation and from the Wuliu Quarry have been published by Yin *et al.* (2010, see for further references).

Biostratigraphy. –The quarry crosses through the boundaries of the regional Qiadongian-Wulingian series, Duynian-Taijiangian stages and the *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* and the *Oryctocephalus indicus* zones (Zhao *et al.* 2005a). The Wulingian Series, Taijianian Stage and *Oryctocephalus indicus* Zone are defined by the first occurrence of *O. indicus*. In the Wuliu Quarry, the first occurrence of *O. indicus* is in level FZX25 (Figs 5, 7), approximately 2 m above the base of the quarry and approximately 52.5 m above the base of the Kaili Formation.

The *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone is the same as the *Ovatoryctocara granulata-Bathynotus holopygus* Zone (Yuan *et al*. 2001, 2002; Zhao *et al*. 2005a, 2007), but specimens of the index fossil "*Ovatoryctocara granulata*" were misidentified and is here referred to as the *Ovatoryctocara* cf. *granulata*. In addition, this zone has also been referred to as the *Bathynotus-Nangaops* Zone (Zhao *et al.* 2001a, b), *Bathynotus holopygus-Ovatoryctocara granulata* Zone (Zhao *et al*. 2007), *Bathynotus holopygus-Ovatoryctocara* cf. *granulata* Zone (Yuan *et al.* 2011, Zhao *et al.* 2011), *Ovatoryctocara granulate* [sic] Zone (Zhao *et al*. 2010) and *Bathynotus-Redlichia* Zone (Lin 2009).

Common taxa in the lower 2 m of the quarry (Fig. 7; *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone) are the ptychopariids *Balangcunaspis subcylindricus* Yuan & Zhao *in* Yuan *et al.*, 1997, *Nangaops danzhaiensis* (Zhou *in* Lu *et al.*, 1974a), and *Probowmania nankingensis* Lin, 1965, and the oryctocephalid *Protoryctocephalus wuxunensis* Zhou *in* Lu *et al.*, 1974b. Rarer species include the corynexochid *Olenoides hubeiensis* (Sun, 1984); the oryctocephalids *Oryctocephalops guizhouensis* Zhao & Yuan *in* Yuan *et al.*, 2002, *Ovatoryctocara* cf. *granulata* and *Protoryctocephalus balangensis* Zhao & Yuan *in* Yuan *et al.*, 2002; the redlichiid *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998, and the articulate brachiopod *Eoconcha* sp. *Pagetia taijiangensis* and *Xingrenaspis xingrenensis* Yuan & Zhou *in* Zhang *et al.*, 1980, are also rare, but are limited to 40 cm below the FAD of *O. indicus*.

Common taxa in the upper 2.35 m of the quarry (Figs 5, 7; *Oryctocephalus indicus* Zone) are the ptychopariids *Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980) and *Xingrenaspis xingrenensis*; the corynexochid *Olenoides paraptus* Zhao *et al.*, 1994c; the eodiscoid *Pagetia taijiangensis,* which is the numerically dominate taxon, and the inarticulate brachiopod *Linnarssonia* cf. *constans*. Rarer species include the ptychopariids *Danzhaiaspis quadratus* Yuan & Zhou *in* Zhang *et al.*, 1980 and *Nangaoia* (*Shilengshuia*) *conica* Yuan & Zhao *in* Yuan *et al.*, 2002; and the oryctocephalids *Curvoryctocephalus taijiangensis* Zhao & Yuan *in* Yuan *et al.*, 2002, *Euarthricocephalus taijiangensis* Yuan & Zhou *in* Yuan *et al.*, 2002, *Metabalangia yupingensis* Qian & Yuan *in* Zhang *et al.*, 1980, *Metarthrioceiphalus spinosus* Zhao & Yuan *in* Yuan *et al.*, 2002, and *Oryctocephalus indicus*.

Regional index fossils are relatively rare in the quarry. The "lower Cambrian" taxon *Redlichia* is represented by just 12 specimens (10 minimum individuals) from eight levels, including meraspids, librigena, or cranidia too incomplete to allow specific identification. The "lower Cambrian" taxon *Ovatoryctocara* cf. *granulata* is more common, but is still known from only 12 specimens (10 minimum individuals) from eight levels. The last appearance datum (LAD) of both taxa is in level FZX29, approximately 20 cm below level FZX25 that contains the FAD of *O. indicus*. The "middle Cambrian" taxon *Oryctocephalus indicus* is more common, but individual levels contain one to three minimum numbers of individuals. Seventy-seven specimens (minimum 60 individuals) of *O. indicus* have been identified from the quarry. Nearly every level from FZX25 to FZX1 (top of section) contains one or more specimens of *O. indicus*.

Analysis of the taxa ranges at or near the FAD of *O. indicus* indicate that the faunal changes illustrated in figure 7 are relatively accurate and not the result of small sample sizes. The probability of each species occurring in an adjacent level(s) to its last or first occurrence was determined. Using the binomial distribution, this analysis evaluate the probability of the minimum number of individuals of that species found in that adjacent level (0), the expected minimum number to be found (mean • sample size), and the sample size (n = minimum number of individuals from that level). The sample size increased as the next level up (if the LAD of the species is below the FAD of *O. indicus*) or down (if the FAD of the species is near the FAD of *O. indicus*) is added to the analysis. The sample size would be the increased and the probability is recalculated. The thin dashed lines in figure 7 show the potential extention of taxa ranges based on this analysis ($p > 0.05$). Most extensions range through the relatively barren zone FZX26 to 28. Those potentially ranging upwards from this barren zone include *Olenoides hebeiensis* into FZX24 and *Redlichia takooensis*, *Ovactoryctocara* cf. *granulata*, *Oryctocephalops guizhouensis*, and *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980) into FZX25. Those potentially ranging downwards from this barren zone include *Oryctocephalus indicus*, and *Olenoides paraptus* into FZX29; *Nangaoia* (*Schilengshuia*) *conica* to FZX30 and *Euarthriocephalus taijiangensis* into FZX33. Analyses were not done on *Nangaoia* sp., *Metabalangia yupingensis*, *Curvoryctocephalus taijiangensis*, *Metarthriocephalus spinosus* or *Oryctocephalus elongatus*? (Zhao *et al*., 1997) based on their overall rarity and stratigraphic distance away from the FAD of *O. indicus*.

Discussion

Comparison to previous work. – Zhao *et al.* (2005a, fig. 7) provided a detailed range chart from a 4 m section across the proposed boundary located about 10 m away from the proposed GSSP. The taxa reported here are less diverse than that reported in that preliminary report. Differences in the reported taxa result from this study's more conservative approach to specific identification due to tectonic distortion, mold and cast preservation, and compaction of specimens, which resulted in the over-splitting of taxa. For example, Zhao *et al.* (2005a) identify *Nangaops brevicus* [sic = *brevis*] Yuan & Sun *in* Zhang *et al.*, 1980, *N. danzhaiensis, N. elongatus* Yuan & Sun *in* Zhang *et al.*, 1980*, N. latilimbatus* Yuan *in* Zhang *et al*., 1980, and *N. nangaoensis* Yuan *in* Zhang *et al.*, 1980, from below the boundary interval. This study recognizes that the differences between these species are the result of tectonic distortion and compaction of specimens and placed all five species into *N. danzhaiensis*. Most other differences in trilobite identification are probably the result of the two different approaches to identification procedures. Assignment of taxonomic names was done without reference to previously published taxonomic stratigraphic ranges.

Another inconsistency in the taxon range above and below the FAD of *O. indicus* include *Euarthricocephalus* Ju, 1983, which was not seen in the quarry section below the FAD. However, the range analysis discussed above indicates that its absence may be due to the taxon's rarity in the section. Genera reported by Zhao *et al.* (2005a) and not identified in this study include: *Arthricocephalus* Bergeron, 1899*, Bathynotus* Hall, 1860, *Chittidilla* King, 1941, *Eokaotaia* Yuan & Zhao, 1994, *Kootenia* Walcott, 1889*, Oryctocephalites* Resser, 1939, *Paramgaspis* Yuan & Zhao *in* Yuan *et al.*, 1997, *Parashuiyuella, Qiannanagraulos* Yuan & Zhao *in* Yuan *et al.*, 1997, and *Yuehsienszella* Zhang, 1957. These inconsistencies may be the result of the number of specimens collected, larger stratigraphic section collected (40 m above and below the FAD of *O. indicus*), preservation, tectonic distortion, and/or oversplitting of taxa.

FAD of Oryctocephalus indicus. – The first occurrence of *Oryctocephalus indicus* is presently being considered as the biohorizon to mark the base of the Cambrian Stage 5 (see Zhao *et al.* 2005a, Sundberg 2009, McCollum & Sundberg 2010). This study demonstrates that this biohorizon (level FZX25) marks a significant change in trilobite faunas in southwestern China. The occurrence of oryctocephalids and other polymeroids above and below the FAD and the lack of lithologic changes at the FAD suggest that the appearance of *O. indicus* is not environmentally controlled. However, the carbon excursion (Lin 2011) just below the FAD and the abundant occurrence of *Pagetia taijiangensis* and *Linnarssonia* cf. *constans* beginning at this horizon does suggest that some aspect of the regional environment had changed. The presence of *Linnarssonia constans* in the lower Cambrian *Redlichia chinensis-Kootenia gimmelfarbi* Zone of Malyi Karatau in Kazakhstan (Holmer *et al.* 2001, Leonid Popov 2010, personal communication) suggests that the lineage migrated into South China due to some change in the environmental conditions.

The 20.5 cm relatively barren zone below the FAD of *O. indicus* (levels FZX 26–28) suggests that level FZX25 may not document the lowest occurrence of *O. indicus*. However, the lack of *O. indicus* below the relatively barren zone and the presence of other oryctocephalids suggest that if the FAD of *O. indicus* is not in level FZX25, then this level is considerably close to the actual FAD in the Kaili Formation. Analysis of range extentions suggests that *O. indicus* could potentially extend down to FZX29, approximately 30 cm below the FAD of *O. indicus* in the Wului Quary.

The results from here study confirm previously works (Yuan *et al*. 1997; Sundberg *et al*. 1999, 2010; Zhao *et al*. 2001a, 2001b, 2004, 2005a, 2007) that the FAD of *O. indicus* at Wuliu-Zengjiayan section is appropeate candidate for the GSSP of the Cambrian Stage 5 or Series 3.

Systematic paleontology

All illustrated specimens are from the Wuliu Quarry and are deposited in the Museum of College of Resource and Environment Engineering, Guizhou University (GK). Photographed specimens were coated with colloidal graphite or India ink (latex casts) and ammonium chloride sublimate. Material counts presented below are based on the number of positives or negatives, whichever is higher, of cranidia and pygidia counted as described above in the methods.

Suborder Eodiscina Kobayashi, 1939
Family Eodiscidae Raymond, 1913

Genus *Pagetia* Walcott, 1916

Type species. – *Pagetia bootes* Walcott, 1916.

***Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997)**
Figure 8A–Y

1997 *Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*); p. 499, pl. 1, figs 1–4.
2001a *Pagetia* sp. – Zhao *et al*., pl. 1, fig. 4.
2001b *Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Zhao *et al.*, pl. 6, fig. 7.
2002 *Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997). –Yuan *et al.*, pp. 79, 230, pl. 2, figs 1–4, 6–15.
2002 *Pagetia significans* Etheridge, 1902. – Yuan *et al.*, pp. 80, 230, pl. 4, figs 3–10, pl. 5, figs 1, 6–11, pl. 57, figs 1–2.
2005a *Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Zhao *et al.*, pl. 6, fig. 7.
2007 *Pagetia taijiangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Zhao *et al.*, fig. 3k.
2009 *Pagetia* cf. *P. significans* Etheridge, 1902. – Lin & Yuan, fig. 2.
2010b *Pagetia danzhaiensis* Zhang (*in* Zhang *et al.*, 1980). – Sundberg *et al*., fig. 1.

Material. – 4096 cranidia, 4871 pygidia, 26 complete or partial shields.

Emended diagnosis. – *Pagetia* with cranidia with poorly defined anterior border, shallow scrobicules, smooth surface, weak ocular ridges, and tapered glabella with occipital spine and shallow glabellar furrows. Pygidia elongated with anterior lateral corners occurring 1/2 pleural field with to axis and flexing about 30° posterio-laterally, shallow pleural furrows, axis with 4–5 axial rings, weak axial nodes, sharply rounded terminal piece, and thin terminal spine; and smooth surface.

Remarks. – *Pagetia taijiangensis* is the most common trilobite in the upper half of the quarry. Both *P. taijiangensis* and *P. significans* have been identified from this portion of the Kaili Formation (Yuan *et al.* 2002). *Pagetia significans* specimens from Australia (Jell 1975) are very similar to *P. taijiangensis* from the Kaili Formation. *Pagetia taijiangensis* differs from *P. significans* (based on specimens illustrated by Jell 1975) in the cranidia having a poorly defined anterior border (except internal molds, Fig. 8W), shallower scrobicules, smooth surface, and stronger ocular ridges. The pygidia differ in having the anterior lateral corners occurring closer to the axis and flexing at about 30° instead of 45°, shallow pleural furrows, and smooth surface.

A few pygidia from the Kaili Formation have a very thin terminal spine (Fig. 8T, U), but this feature is commonly broken leaving only a small bump on the terminal segment of the pygidial axis. The third thoracic segment also has a very thin spine (Fig. 8V, Y), which is rarely preserved.

Pagetia taijiangensis differs from the type material of *P. danzhaiensis* Zhang *in* Zhang *et al*., 1980, the latter shows very few or absent (or preserved) scrobicules on the anterior border, a more rounded pygidium with granules and a rounded terminal piece (also see Yuan *et al.* 2002, pl. 3, figs 9, 10). *Pagetia bilobata* Lu & Chien *in* Yin & Lee, 1978, and *P. salva* Zhang *in* Zhang *et al*., 1980, differ from *P. taijiangensis* in a parallel sided glabella and rounded occipital "spine". However, Zhang (*in* Zhang *et al.* 1980, pl. 13, figs 9, 10) and Yuan *et al.* (2002, pl. 5, fig. 4) illustrate specimens of *P. bilobata* with a sharp occipital spine. If these specimens are correctly assigned, then the presence and absence of the occipital spine may be a preservation difference as can be seen in some of the specimens of *P. taijiangensis* illustrated by Yuan *et al.* (2002). Without further detailed study, *Pagetia bilobata* and *P. salva* are not included into *P. taijiangensis*.

Pagetia miaobanpoensis Yuan & Huang (*in* Yuan *et al.*, 2002) differs from *P. taijiangensis* in the glabella having a prominent furrow separating the frontal lobe from the remaining glabella and a pygidium with fewer axial rings and prominent axial ring nodes. A single specimen (Yuan *et al.* 2002, pl. 3, fig. 5) has a wide postaxial spine; other illustrated pygidia show breakage at the posterior lobe where a spine was attached, but not a large scar that would correspond to such a wide spine seen in the single specimen.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* and *Oryctocephalus indicus* zones: Wuliu Quarry level FZX1–29; Wuliu-Zengjiayan and Miaobanpo sections, China.

Order Redlichiida Richter, 1933
Suborder Redlichiina Moore (*in* Harrington *et al*., 1959)
Superfamily Redlichiacea Poulsen, 1927
Family Redlichiidae Poulsen, 1927

Genus *Redlichia* (*Redlichia*) Cossmann, 1902

Type species. – *Hoeferia noetlingi* Redlich, 1899.

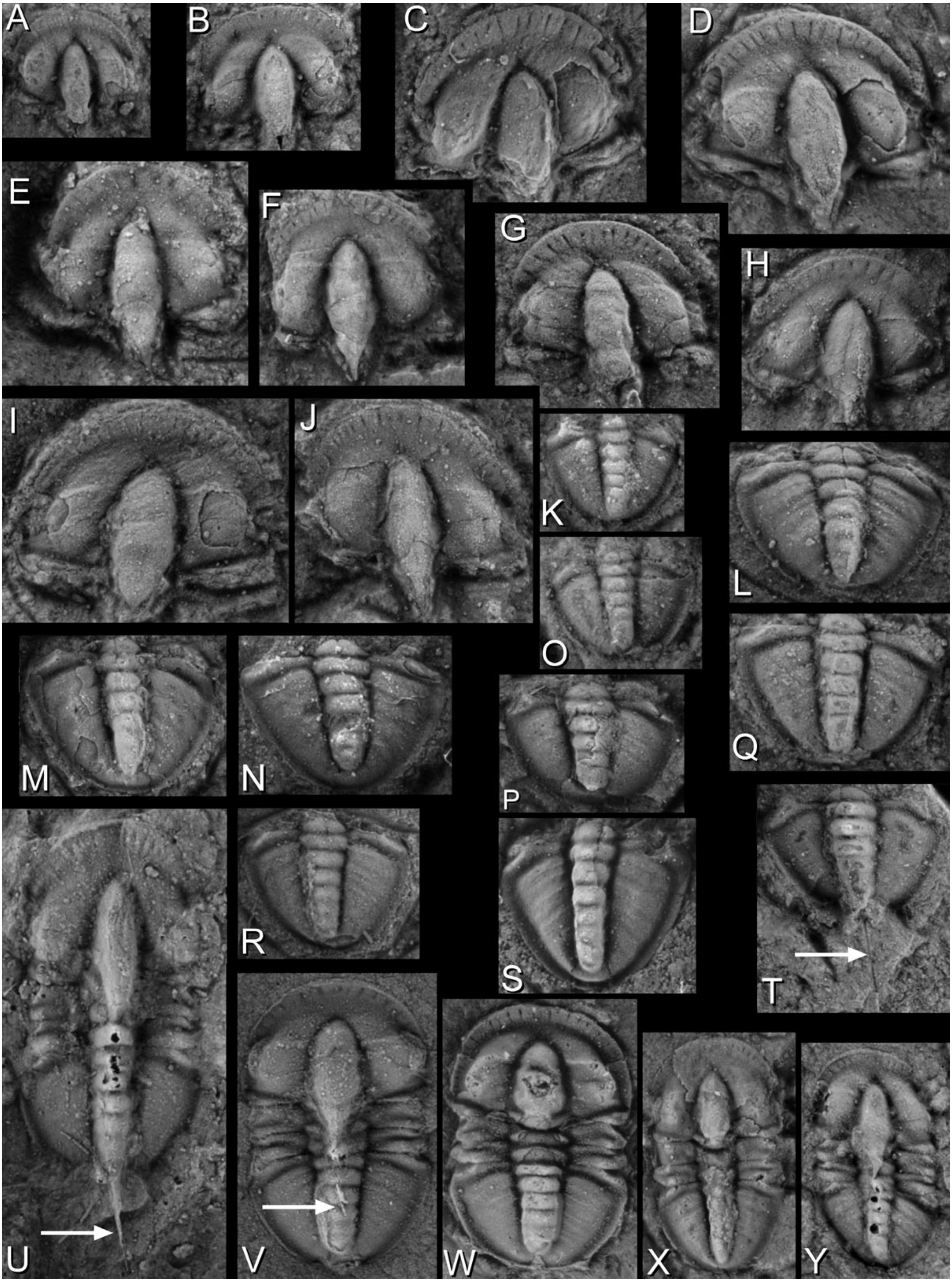
***Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998**
Figure 9A–C

1998 *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao; p. 52, pl. 1, figs 3, 3a.
1999 *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998. – Guo *et al.*, pp. 159, 163, pl. 1, figs 1a, b, 2a, b, pl. 2, figs 3, 5–7.
2001a *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998. – Zhao *et al.*, pl. 1, fig. 11.
2002 *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998. – Yuan *et al.*, pp. 83, 231, pl. 6, figs 1–6.
2007 *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998. – Zhao *et al.*, fig. 4j.
2010b *Redlichia taijiangensis* Guo & Zhao, 1998. – Sundberg *et al*., fig. 1.

Material. – 5 cranidia, 1 librigena, 6 partial shields.

Remarks. – Only a few specimens can be firmly established as this species. Diagnostic features include the presence of

Figure 8. *Pagetia taijiangensis* Yuan & Zhao *in* Yuan *et al.*, 1997, all figures × 11. • A – cranidium, partially exfoliated, GK B3 0003, FZX20. • B – cranidium, partially exfoliated, GK B3 0004, FZX11. • C – cranidium, partially exfoliated, GK B3 0005, FZX20. • D – cranidium, partially exfoliated, GK B3 0006, FZX20. • E – cranidium, not exfoliated, GK B3 0007, FZX9. • F – cranidium, not exfoliated, GK B3 0008, FZX29. • G – cranidium, exfoliated, GK B3 0009, FZX20. • H – cranidium not exfoliated, GK B3 0010, FZX18. • I – cranidium, partially exfoliated, GK B3 0011, FZX28. • J – cranidium, partially exfoliated, GK B3 0012, FZX12. • K – pygidium, not exfoliated, GK B3 0013, FZX17. • L – pygidium, not exfoliated, GK B3 0014, FZX9. • M – pygidium, partially exfoliated, GK B3 0015, FZX23. • N – pygidium, not exfoliated, GK B3 0016, FZX8. • O – pygidium, not exfoliated, GK B3 0017, FZX17. • P – pygidium, partially exfoliated, GK B3 0018, FZX16. • Q – pygidium, exfoliated, GK B3 0019, FZX24. • R – pygidium, not exfoliated, GK B3 0020, FZX8. • S – pygidium, not exfoliated, GK B3 0021, FZX20. • T – pygidium, exfoliated, arrow pointing to thin terminal spine, GK B3 0022, FZX8. • U – shield, not exfoliated, latex cast, arrow pointing to thin terminal spine, GK B3 0023, FZX9. • V – shield, not exfoliated, latex cast, arrow pointing to thin thoracic axial spine, GK B3 0024, FZX5. • W – shield, exfoliated, GK B3 0025, FZX20. • X – shield, partially exfoliated, GK B3 0026, FZX11. • Y – shield, not exfoliated, latex cast, GK B3 0027, FZX17.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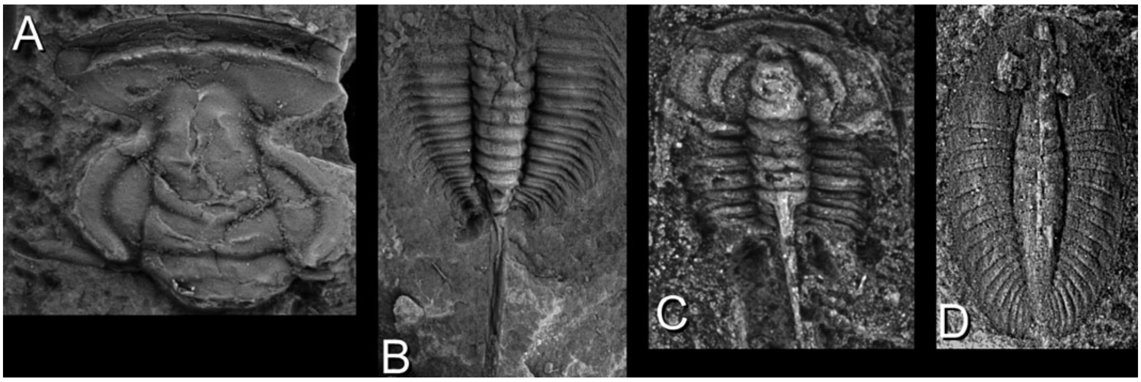


Figure 9. A–C – *Redlichia* (*Redlichia*) *takooensis longspina* Guo & Zhao, 1998. • A – cranidium, partially exfoliated, GK B3 0028, × 7, FZX29. • B – thorax with terminal spine, exfoliated, GK B3 0029, × 5, FZX44. • C – partial shield, exfoliated, GK B3 0030, × 10, FZX32. D – *Burlingia ovata* Zhou & Yuan *in* Zhang *et al.*, 1980. • D – complete shield, exfoliated, GK B3 0031, × 7, FZX29.

a prefrontal area, sharper acute angle between the anterior facial suture and the anterior border, and prominent spine on the thorax. The 12 specimens from the Wuliu Quarry have been assigned to this species, but most specimens are too incomplete or meraspids to allow specific identification. It is possible that some specimens may represent the co-occurring species *Redlichia* (*Redlichia*) *taijiangensis* Guo & Zhao, 1998 (Yuan *et al.* 2002).

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX29, 31–33, 35, 40, 44, 46; Wuliu-Zengjiayan section, China.

Uncertain order
Family Burlingiidae Walcott, 1908

Genus *Burlingia* Walcott, 1908

Type species. – Burlingia hectori Walcott, 1908.

***Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.,* 1980)**
Figure 9D

1980 *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*); pp. 380, 381, pl. 110, fig. 1.
2001b *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980). – Zhao *et al.*, pl. 7, fig. 4.
2002 *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 130, 131, 254, 255, pl. 38, figs 3–8, p. 39, figs 1–4.
2005 *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980). – Lin *et al.*, fig. 3b.
2005a *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980). – Zhao *et al.*, pl. 7, fig. 4.
2005b *Burlingia ovata* Zhou & Yuan (*in* Zhang *et al.*, 1980). – Zhao *et al.*, pl. 3, fig. 11.

Material. – 1 pygidium, 4 complete shield.

Remarks. – The difference between *B. ovata* and *B. multisegmata* Zhao *et al. in* Yuan *et al.*, 2002, are the latter having longer palpebral lobes and 16 thoracic segments vs. 14 segments in *B. ovata*. Other differences mentioned by Yuan *et al*. (2002, p. 255) are based on the width of the shield, axial region, and glabella and strongly divergent anterior braches of facial sutures. These wider (tr.) features may be the result of tectonic deformation. The differences between *B. ovata* and *B. primitiva* Zhao *et al. in* Yuan *et al.*, 2002 are the latter having shorter palpebral lobes, more conical glabella and 13–14 thoracic segments. Other differences mentioned by Yuan *et al.* (2002, p. 255) are based on the width (tr.) and shorter (sag.) shield and gently divergent anterior braches of facial sutures. These features also may be the result of tectonic deformation of the specimens. The stratigraphic ranges of *B. ovata* and *B. multisegmenta* overlap in the Miaobanpo section (Yuan *et al.* 2002).

Zhao *et al.* (2005a, p. 66, 2007, fig. 1) report the range of *B. ovata* as occurring only above the FAD of *O. indicus*. However in this study, *B. ovata* was found only below the FAD of *O. indicus*. This discrepancy in ranges is presently unexplained; it may be to the rarity of the species in the section.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX29, 31, 34; *Oryctocephalus indicus* Zone: Wuliu-Zengjiayan and Miaobanpo sections, China.

Order Corynexochida Kobayashi, 1935
Family Dorypygidae Kobayashi, 1935

Genus *Olenoides* Meek, 1877

Type species. – Paradoxides (?) *nevadensis* Meek, 1870.

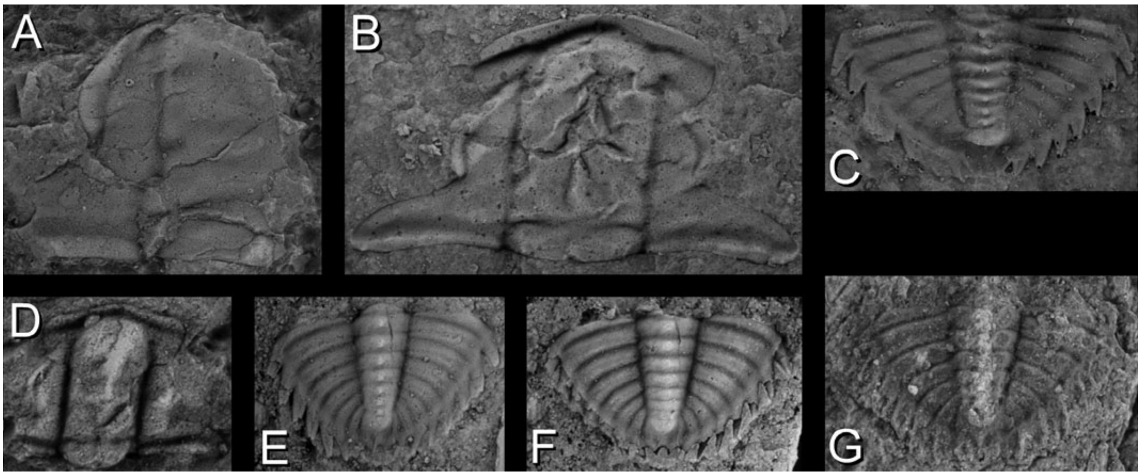


Figure 10. *Olenoides hubeiensis* (Sun, 1984). • A – partial large cranidium, partially exfoliated, GK B3 0032, × 4, FZX31. • B – cranidium, exfoliated, GK B3 0033, × 5, FZX46. • C – pygidium, not exfoliated, latex cast, × 5, GK B3 0034, FZX35. • D – cranidium, exfoliated, GK B3 0035, × 7, FZX38. • E, F – pygidium, GK B3 0036, × 7, FZX31; E – latex cast showing axial nodes, F – exfoliated, most axial nodes absent. • G – pygidium, calcite coated, GK B3 0037, × 7, FZX38.

Olenoides hubeiensis **(Sun, 1984)**
Figures 10A–G

1984 *Fuchouia huberiensis* Sun; p. 350, pl. 134, fig. 13.
1984 *Kootenia* sp. 1 Sun, pl. 1, figs 5, 6.
1984 *Kootenia* sp. 2 Sun, pl. 1, fig. 7.
1997 *Mengzia* sp. Yuan *et al.*, p. 503, pl. 1, fig. 7.
1997 *Olenoides abnormis* Yuan & Zhao (*in* Yuan *et al.*), pp. 501, 502, pl. 1, fig. 11, pl. 2, figs 11, 12.
1997 *Olenoides octaspinus* Yuan & Zhao (*in* Yuan *et al.*), p. 502, pl. 1, figs 9, 10, pl. 2, fig. 10.
2002 *Olenoides abnormis* Yuan & Zhao (*in* Yuan *et al.*). – Yuan *et al.*, pp. 92, 93, 233, pl. 10, figs 12–14.
2002 *Olenoides hubeiensis* (Sun, 1984). – Yuan *et al.*, pp. 92, 93, 233, pl. 10, figs 1–11.
2002 *Olenoides transversus* Zhao & Yuan (*in* Yuan *et al.*), pp. 93, 94, 233, pl. 11, figs 7, 8, not pl. 13, fig. 10 (= *Olenoides paraptus*).
2007 *Olenoides hubeiensis* (Sun, 1984). – Zhao *et al.*, fig. 4D, E.

Material. – 4 cranidia, 16 pygidia.

Emended diagnosis. – *Olenoides* with cranidium with parallel sided glabella and prominent ocular ridges. Pygidium with six to seven axial rings, axial nodes, and seven to eight pairs of pleural spines.

Remarks. – The pygidia in the quarry samples have six to seven axial rings. It is very likely that *O. abnormis* Yuan & Zhao *in* Yuan *et al.*, 1997, is the same species with transverse elongation due to tectonic distortion. The two illustrated pygidia of *Olenoides transversus* Zhao & Yuan *in* Yuan *et al.*, 2002 (pl. 11, figs 7, 8; no holotype was designated for this species) are tectonically elongated (tr.) and have the same number of axial rings and pygidial spines as *O. hubeiensis* and are included in this species.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX31–32, 35, 36, 38, 40, 41, 43–46; Qinglinchong and Wuliu-Zengjiayan sections, China.

Olenoides paraptus **Zhao, Ahlberg & Yuan, 1994c**
Figure 11A–N

1983 *Kootenia jialaoensis* Lu & Chien, 1978. – Lu & Qian, pp. 25, 26, pl. 3, figs 2, 3.
1994c *Olenoides paraptus* Zhao *et al.*; pp. 370, 371, 374, 375, pl. 1, figs 1–4, 6–9.
1997 *Olenoides jialaoensis* (Lu & Chien, 1978). – Yuan *et al.*, p. 501, pl. 1, fig. 8.
1999 *Olenoides jialaoensis* (Lu & Chien, 1978). – Yuan *et al.*, pl. 2, figs 12–14.
2001b *Olenoides jialaoensis* (Lu & Chien, 1978). – Zhao *et al.*, pl. 6, fig. 6.
2002 *Olenoides paraptus* Zhao *et al.*, 1994c. – Yuan *et al.*, pp. 91, 92, 232, pl. 11, figs 1–6, pl. 12, figs 1–8, pl. 13, figs 1–6.
2002 *Olenoides transversus* Zhao & Yuan (*in* Yuan *et al.*), pp. 93, 94, 233, pl. 13, fig. 10, not pl. 11, figs 7, 8 (= *Olenoides hubeiensis*).
2005a *Olenoides jialaoensis* (Lu & Chien, 1978). – Zhao *et al.*, pl. 6, fig. 6.
2005b *Olenoides paraptus* Zhao *et al.*, 1994c. – Zhao *et al.*, pl. 3, fig. 3.
2007 *Olenoides paraptus* Zhao *et al.*, 1994c. – Lin, fig. 1A.
2010b *Olenoides transversus* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Sundberg *et al.*, fig. 1.

Material. – 83 cranidia, 60 pygidia, 7 partial or complete shields.

Emended diagnosis. –*Olenoides* with cranidium with anteriorly expanding glabella and moderate strength to weak ocular ridges. Pygidium with five axial rings, axial nodes, six pairs of pleural spines.

Remarks. – *Olenoides paraptus* is best recognized by the five pygidial axial rings, five strong interpleural furrows, and six pairs of pygidial spines. *Olenoides jialaoensis* (Lu & Chien, 1978) *in* Yuan *et al*. (1997) differs in having a more rectangular shaped glabella but this could be the result of tectonic deformation. The type specimen of *Kootenia jialaoensis* Lu & Chien, 1978, is a partial cranidium and does not have the features to characterize a species of *Olenoides*. The cranidium of *O. transversus* (Yuan *et al*., pl. 13, fig. 10; no holotype was designated for this species) is most likely a tectonically distorted specimen of *O. paraptus* and is included into this species.

Fragments composed of a thick exoskeleton with a granular surface similar to *Olenoides paraptus* are found at FZX20, 26, and 27. None of the fragments are large enough to allow specific identification. These occurrences are marked with question marks in Fig. 7. Zhao *et al.* (2007, fig. 1) report this taxon from the upper 8.5 m of the *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone, but no specimens below FZX25 were identified in this study.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* and *Oryctocephalus indicus* zones: Wuliu Quarry levels FZX1–19, ?20, 21, 23–25, ?26, ?27; Wuliu-Zengjiayan and Miaobanpo sections, China.

Family Oryctocephalidae Beecher, 1897

Remarks. – Most of the taxa assigned to this group are relatively easy to identify, although like the ptychopariids (see below), the identification can be questionable due to taphonomic problems, such as compression and tectonic deformation. In addition, the collapse of the frontal lobe due to the *in situ* hypostome obscures the presence and shape of the pits and furrows on the glabella.

Subfamily Oryctocephalinae Beecher, 1897

Genus *Oryctocephalus* Walcott, 1886

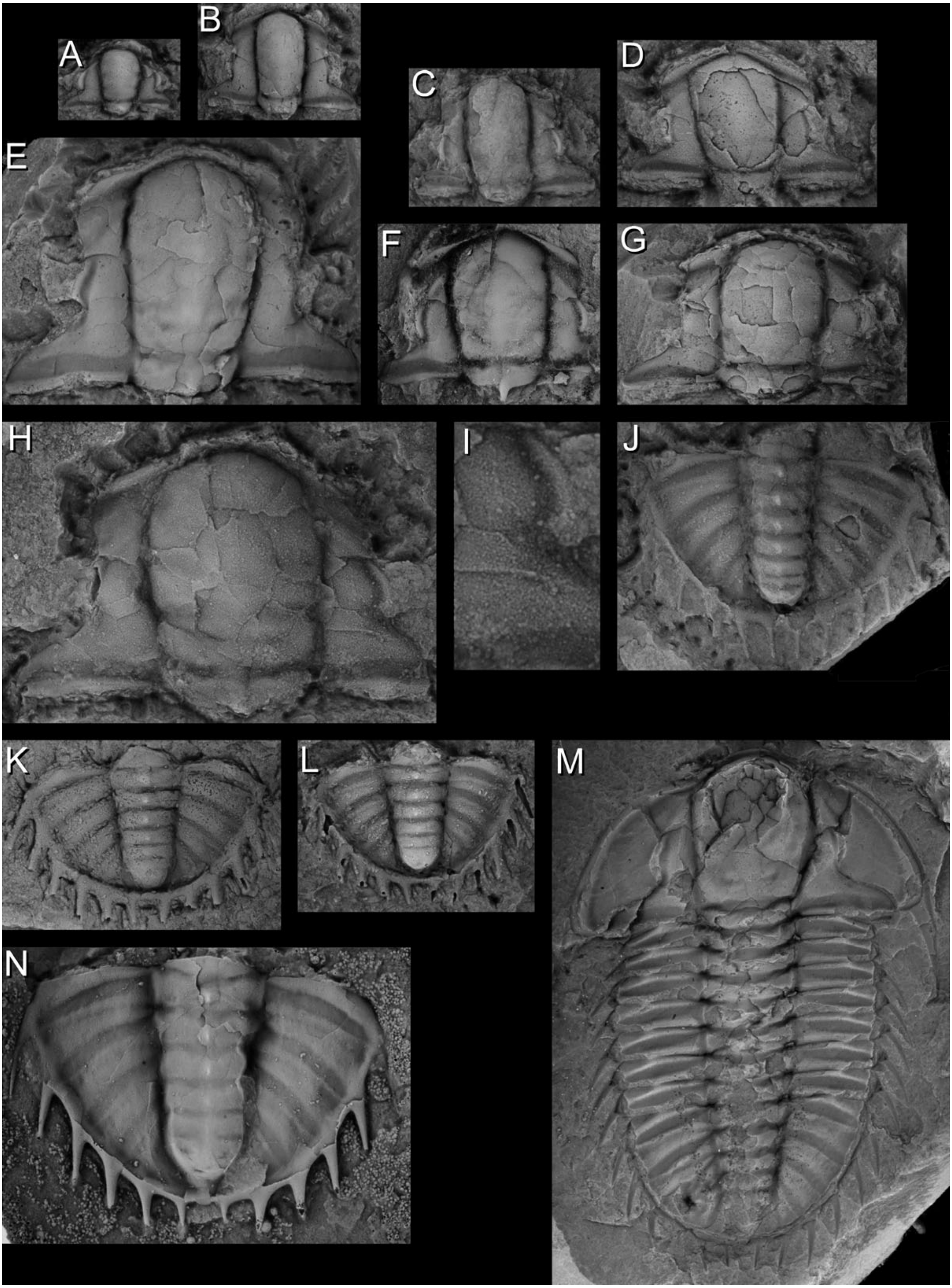
Type species. – *Oryctocephalus primus* Walcott, 1886.

Remarks. – Yuan *et al.* (2002) subdivided the genus into two subgenera, *Oryctocephalus* and *Eoryctocephalus*. The differences between the two subgenera are significant, but need to be tested with cladistic analysis. *Eoryctocephalus* has more primitive features than *Oryctocephalus* such as wider pleural lobes and fewer pygidial segments. These features may not be enough to separate the taxa.

***Oryctocephalus indicus* (Reed, 1910)**
Figure 12A–L

1910 *Zacanthoides indicus* Reed; pp. 9, 10, pl. 1, fig. 15.
1910 *Oryctocephalus* cf. *reynoldsi* Reed, p. 12, pl. 1, figs 22, 23.
1934 *Oryctocephalus orientalis* Saito (in part), pp. 230, 231, pl. 25, fig. 21, not figs 17–20, 22 = *O. orientalis* Saito, 1934.
1934 *Oryctocephalus kobayashii* Saito, pp. 231, 232, pl. 25, figs 23–25.
1938 *Oryctocephalus indicus* (Reed, 1910). – Resser, p. 38.
1944 *Oryctocephalus indicus* (Reed, 1910). – Kobayashi, p. 33.
1967 *Oryctocephalus indicus* (Reed, 1910). – Kobayashi, p. 487, figs 7–11a, b.
1974b *Oryctocephalus incurvus* Lu & Chien (*in* Lu *et al.*), p. 101, pl. 39, fig. 8.
1980 *Oryctocephalus* cf. *incurvus* Lu & Chien (*in* Lu *et al.*, 1974a). – Zhang *et al.*, p. 270, pl. 96, figs 13–15.
1983 *Oryctocephalops incurvus* (Lu & Chien, 1974). – Lu & Qian, p. 26, pl. 3, figs 6, 7.
1983 *Oryctocephalops tongrenensis* Lu & Qian, p. 27, pl. 3, figs 4, 5.
1997 *Oryctocephalops tongrenensis* Lu & Qian, 1983. – Yuan *et al.*, pl. 4, figs 8, 9.
1997 *Oryctocephalus indicus* (Reed, 1910). – Jell & Hughes, pp. 34, 35, figs 7a–c, pl. 5, figs 16–19.
1997 *Oryctocephalus indicus* (Reed, 1910). – Sundberg & McCollum, pp. 1073–1077, figs 9.1–9.8, 9.10.

Figure 11. *Olenoides paraptus* Zhao, Ahlberg & Yuan, 1994c. • A – cranidium, not exfoliated, GK B3 0038, × 5, FZX1. • B – cranidium, not exfoliated, GK B3 0039, × 5, FZX9. • C – cranidium, not exfoliated, GK B3 0040, × 3, FZX19. • D – cranidium, partially exfoliated, GK B3 0041, × 5, FZX9. • E – cranidium, not exfoliated, GK B3 0042, × 3, FZX23. • F – cranidium, not exfoliated, latex cast, GK B3 0043, × 3, FZX10. • G – cranidium, partially exfoliated, × 3, GK B3 0044, FZX11. • H, I – cranidium, not exfoliated, × 3, I – enlarged portion showing fine granules, × 6, GK B3 0045, FZX12. • J – pygidium, not exfoliated, × 3, GK B3 0046, FZX9. • K – pygidium, not exfoliated, × 3, GK B3 0047, FZX4. • L – pygidium, not exfoliated, × 3, GK B3 0048, FZX4. • M – shield, mostly exfoliated, × 2, GK B3 0050, FZX7. • N – pygidium, not exfoliated, latex cast, × 3, GK B3 0049, FZX7.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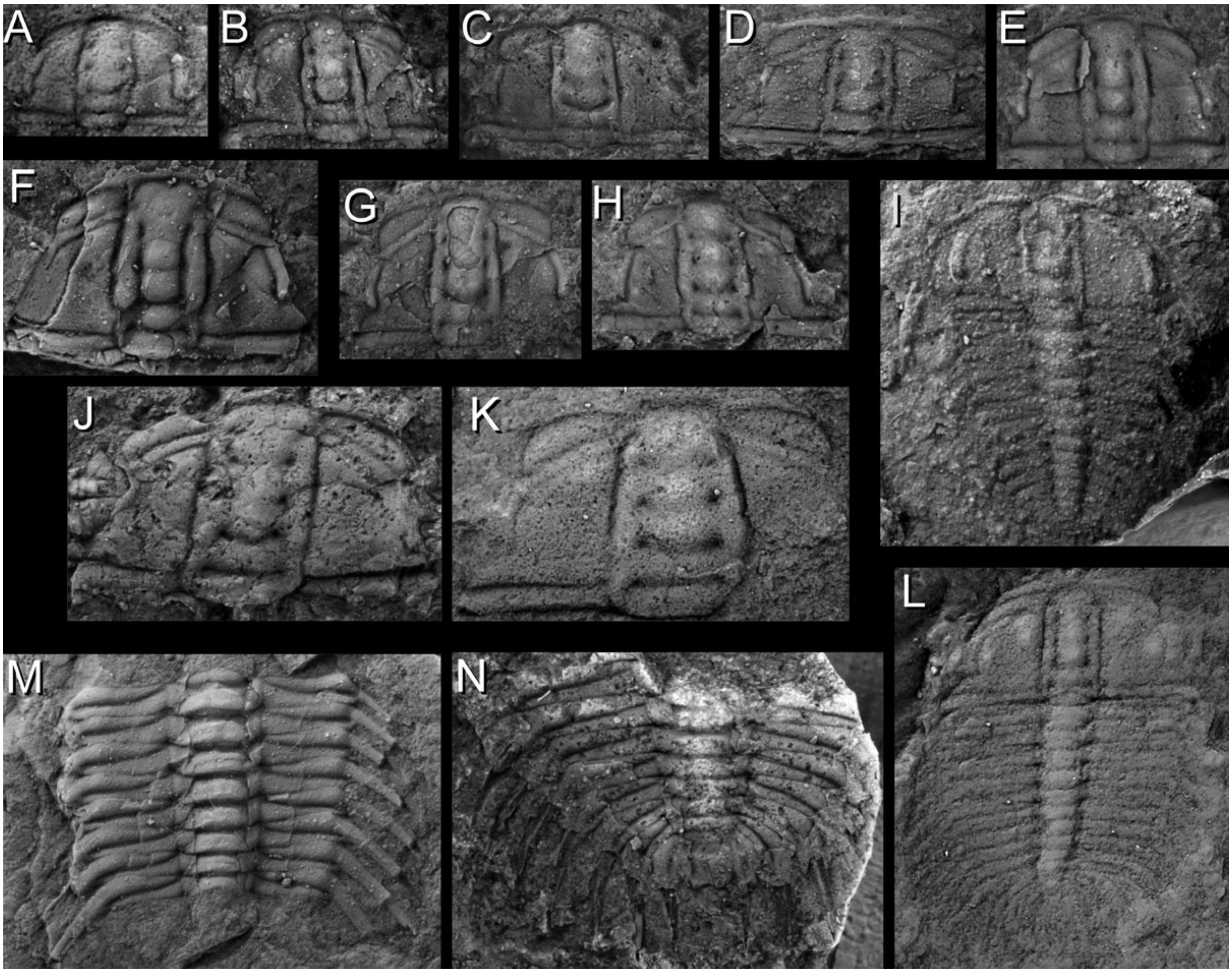


Figure 12. *Oryctocephalus indicus* (Reed, 1910), all figures × 7 unless otherwise noted. • A – cranidium, exfoliated, GK B3 0051, × 10, FZX2. • B – cranidium, partially exfoliated, GK B3 0052, FZX12. • C – cranidium, exfoliated, GK B3 0053, FZX14. • D – cranidium, exfoliated, GK B3 0054, FZX19. • E – cranidium, mostly exfoliated, GK B3 0055, FZX8. • F – cranidium, partially exfoliated, GK B3 0056, FZX11. • G – cranidium, mostly exfoliated, with hypostome impression, GK B3 0057, FZX17. • H – cranidium, exfoliated, GK B3 0058, FZX8. • I – shield, not exfoliated, with hypostome impression, latex cast, GK B3 0059, FZX3. • J – cranidium, exfoliated, GK B3 0060, FZX25. • K – partial cranidium, exfoliated, GK B3 0061, FZX6. • L – nearly complete shield, exfoliated, GK B3 0064, × 5, FZX16. • M – thoracic segments, calcite coated, GK B3 0062, FZX13. • N – thoracic segments and pygidium, mostly exfoliated, GK B3 0063, FZX22.

1997 *Oryctocephalus indicus* (Reed, 1910). – Yuan *et al.*, pl. 4, figs 1–6, 8, 9.

1999 *Oryctocephalus indicus* (Reed, 1910). – Sundberg *et al.*, pl. 1, fig. 3.

1999 *Oryctocephalus indicus* (Reed, 1910). – Yuan *et al.*, pl. 1, fig. 6.

1999 *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 4, fig. 4.

2001 *Oryctocephalus orientalis* Saito, 1934. – Yuan *et al.*, pl. 1, fig. 2.

2001 *Oryctocephalus* (*O.*) *indicus* (Reed, 1910). – Yuan *et al.*, pl. 1, fig. 3.

2001a *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 1, figs 2, 3.

2001b *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 6, figs 1, 8.

2002 *Oryctocephalus* (*Oryctocephalus*) *indicus indicus* (Reed, 1910). – Yuan *et al.*, pp. 100, 101, 237, pl. 17, figs 1–9, pl. 18, figs 1–8, pl. 19, figs 1–4, pl. 20, figs 4–9, pl. 21, fig. 7, pl. 22, fig. 5, pl. 23, figs 1–4, pl. 29, figs 6, 7.

2002 *Oryctocephalus* (*Oryctocephalus*) *indicus latus* (Reed, 1910). – Yuan *et al.*, pp. 101, 102, 237, pl. 20, figs 2, 3, pl. 21, figs 1–3, 5, 6, pl. 22, fig. 2, 7, 8, pl. 28, figs 9, 10.

2002 *Oryctocephalus* (*Oryctocephalus*) *orientalis* Saito, 1934. – Yuan *et al.*, pp. 103, 238, pl. 22, figs 3–6, 9, 10?, pl. 28, figs 6–8.

2003 *Oryctocephalus indicus* (Reed, 1910). – Sundberg & McCollum, pp. 960, 962, pl. 8, figs 9, 12, 13.
2005 *Oryctocephalus indicus* (Reed, 1910). – Lin *et al.*, fig. 3a.
2005a *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 6, fig. 1, 8.
2005b *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 3, fig. 4.
2006 *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pp. 1178–1181, figs 1a–j.
2007 *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, figs 5a–e.
2008 *Oryctocephalus indicus* (Reed, 1910). – Zhao *et al.*, pl. 4, fig. 13.
2009 *Oryctocephalus indicus* (Reed). – Luo *et al.*, pl. 9, figs 4–6a.

Material. – 53 cranidia, 6 pygidia, 18 partial or complete shields.

Diagnosis. – See Jell & Hughes (1997) and Sundberg & McCollum (1997).

Remarks. – The differences between *O.* (*O.*) *indicus indicus* and *O.* (*O.*) *indicus latus* are the result of tectonic distortion with the latter being transversely elongated. They also occur in the same horizons in the Wuliu-Zengjiayan and Miaobanpo sections (Yuan *et al.* 2002). Specimens of *O. orientalis* Saito, 1934, illustrated by Yuan *et al.* (2002) fall within the morphological range of *O. indicus*.

Zhao *et al.* (2006) redefined the morphological range of *O. indicus* based primarily on the material from the Kaili Formation. In this redefinition, *O. indicus* was given a range of 1 to 3 transglabellar furrows. This was probably the primary justification for adding *Oryctocephalus reticulatus* (Lermontova, 1940) to their synonymy list. Korovnikov (2001, personal communication 2010) has also suggested that *O. reticulatus* is synonymous with *O. indicus.* The type material of *Oryctocephalina reticulata* Lermontova, 1940, is unlike subsequent material illustrated as *Oryctocephalus reticulatus* (Lermontova) by Tchernysheva (1962) and Shabanov *et al.* (2008a, b). The type material has a strongly curved anterior border opposed to the slightly curved anterior border of later illustrated material. The specimens later illustrated as *Oryctocephalus reticulatus* are very similar to *O. indicus*, but differ in having only the S1 transglabellar furrow.

To determine if *O. indicus* and *O. reticulatus* are separate species, a limited study of *O. indicus* from the Kaili Formation and the Emigrant Formation, Nevada, and *O. reticulatus* from the Kuonamka Formation, Siberia was done. All specimens were photographed or viewed under a microscope with low angle light. None of the specimens were whitened due to the humidity while the material was studied at Guizhou University (ammonium chloride sublimate dissolves too quickly in high humidity). Thus the results are biased against observing shallow transglabellar furrows. The study of the *O. indicus* from the Miaobanpo section indicates that the number of transglabellar furrows varies in the specimens. Well-preserved specimens (n = 57) in the mudstone show transglabellar furrows 100% of the cases for the SO and S1 positions; 96% for the S2, and 77% for the S3. In comparison, specimens (n = 68) also preserved in mudstone from a 30 cm interval from Split Mountain section, Nevada (Sundberg & McCollum 2003) show transglabellar furrows 100% of the cases at the SO, S1, and S2 positions and 93% at the S3. Shale specimens (n = 100) from the same Split Mountain 30 cm interval illustrate that compaction has little influence on the number of transglabellar furrows with the furrows present 100% of the cases at the SO, S1, and S2 positions and 98% at the S3. *Orytocephalus reticulatus* shale specimens (n = 93) from two horizons in the Molodo River section show that the transglabellar furrows are present 100% of the cases at the SO and S1, and 41% at the S2, and only 3% at the S3. Most of the specimens of *O. reticulatus* that show furrows at the S2 and S3 positions have glabellar lengths less than 2.5 mm. The disappearance of the furrows in larger specimens is probably an ontogenetic change. This indicates that *O. reticulatus* is not synonymous with *O. indicus*. Further study is being done on both taxa by Mark Webster (personal communication, 2010) using the material from this preliminary study and Elena Naimark (personal communication, 2010) using the large collections of *O. reticulatus* from Russia.

This variation in the number of transglabellar furrows in the Kaili specimens may be the result of: different species being present; morphological variation in the Chinese population (the same variation is seen in the coeval *O. nyensis* Palmer *in* Palmer & Halley, 1979 from Nevada – Sundberg & McCollum 1997) and/or tectonic distortion. Many of the specimens from the Kaili Formation are distorted. A specimen from FZX16 (Fig. 12L) is relatively large, and has perhaps only two transglabellar furrows, but the surface of the specimen is weathered. The lowest horizon (FZX25) has two well-preserved cranidia with all three transglabellar furrows (*e.g.*, Fig. 12J).

Occurrence. – *Oryctocephalus indicus* Zone: Kaili Formation, Wuliu Quarry levels FZX1–4, 6–9, 11–25; Wuliu-Zengjiayan and Miaobanpo sections, China; Emigrant Formation, Split Mountain section, Nevada, USA; Monola Formation, California and Nevada, USA; Maozhuangian Stage, Spiti, India; Mansanri Formation, Korea.

***Oryctocephalus elongatus*? (Zhao, Ahlberg & Zhou, 1997)**
Figure 13A

1996 *Oryctocephalina yui* Zhao *et al.*; pl. 2, fig. C.
1997 *Oryctocephalina elongatus* Zhao, Ahlberg & Zhou, pl. 1, figs 1, 5–7.
1997 *Oryctocephalina elongatus guizhouensis* Zhao, Ahlberg & Zhou, pl. 1, fig. 2.
2001b *Oryctocephalina elongata* Zhao, Ahlberg & Zhou, 1997. – Zhao *et al.*, pl. 6, fig. 2.
2002 *Oryctocephalus* (*Eoryctocephalus*) *yui* Zhao & Yuan (*in* Yuan *et al.*), pp. 104, 105, 239, 240, pl. 21, fig. 4, pl. 22, fig. 1, pl. 25, figs 1–8.
2005a *Oryctocephalus (Eoryctocephalus) yui* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 6, fig. 2.
2005b *Oryctocephalus (Eoryctocephalus) yui* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 3, fig. 7.
2010b *Oryctocephalina yui* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Sundberg *et al.*, fig. 1.

Material. – 1 pygidium.

Remarks. – The type species is *Oryctocephalina renticulata* is presently assigned to *Oryctocephalus* (Tchernysheva 1962, Savitsky *et al*. 1972, Shabanov *et al.* 2008a, b), thus *Oryctocephalina elongatus guizhouensis* Zhao, Ahlberg & Zhou, 1997, is transfered to *Oryctorcephalus*.

A single pygidium from FZX4 is questionably assigned to this species due to the long, relatively flat pygidial spines. The first use of the name *Oryctocephalina yui* was by Zhao *et al.* (1996), however, the first description of *O. yui* was in Yuan *et al.* (2002). *Oryctocephalina elongatus* described in 1997 is the senior synonym.

It is possible that *Oryctocephalus elongatus* is tectonically elongated (sag.) where *Oryctocephalus sinicus* Zhao & Yuan *in* Yuan *et al.*, 2002 is tectonically widened (tr.). These two species may represent a single species, but more detailed work is needed to synonymize them. Both species are found in the same horizons in the Wuliu-Zengjiayan section and adjacent horizons in the Miaobanpo section (Yuan *et al.* 2002).

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry level FZX4; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Curvoryctocephalus* Zhao & Yuan (*in* Yuan *et al.*, 2002)

Type species. – *Curvoryctocephalus taijiangensis* Zhao & Yuan (*in* Yuan *et al.*, 2002).

***Curvoryctocephalus taijiangensis* Zhao & Yuan (*in* Yuan *et al.*, 2002)**
Figure 14A–H

2002 *Curvoryctocephalus taijiangensis* Zhao & Yuan (*in* Yuan *et al.*), pp. 112, 244, pl. 26, figs 2–9.
2002 *Curvoryctocephalus sinensis* Zhao & Yuan (*in* Yuan *et al.*), pp. 112, 113, 211, pl. 26, fig. 1.

Material. – 9 cranidia, 2 complete shields.

Remarks. – This species is distinctive with a relatively long (sag.) anterior border and parallel to slightly expanding glabellar with undulatory glabellar furrows (when not distorted by compaction). Only two species have been defined in this genus, *C. taijiangensis* and *C. sinensis* Zhao & Yuan *in* Yuan *et al.*, 2002. Based on a limited number of samples from this study and those illustrated by Yuan *et al.* (2002), these two species are probably conspecific. *Curvoryctocephalus sinensis* longer (sag.) anterior border is probably due to its larger size specimen than those of *C. taijiangensis*. This increase in anterior border length is probably due to ontogenetic variation. Both *C. taijiangensis* and *C. sinensis* are reported from the same stratigraphic horizons in the Miaobanpo section (Yuan *et al.* 2002).

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry levels FZX1–4, 11, 12, 14, 17; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Oryctocephalops* Lermontova, 1940

Type species. – *Oryctocephalops frishenfeldi* Lermontova, 1940.

***Oryctocephalops guizhouensis* Zhao & Yuan (*in* Yuan *et al.,* 2002)**
Figures 13B, C

1997 *Oryctocephalops* sp. Yuan *et al.*; pl. 3, fig. 5.
2001a *Oryctocephalops guizhouensis* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 1, figs 5, 6.
2002 *Oryctocephalops guizhouensis* Zhao & Yuan (*in* Yuan *et al.*); pp. 96, 235, pl. 15, figs 4–7, pl. 16, figs 2–7.
2007 *Oryctocephalops guizhouensis* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, figs 4A, B.

Material. – 9 cranidia, 1 pygidium, 1 complete shield.

Remarks. – Distortion causes difficulty in separating cranidia of *Protoryctocephalus wuxunensis, Oryctocephalops guizhouensis* and *Oryctocephalites taijiangensis*

Zhao & Yuan *in* Yuan *et al.*, 2002. The palpebral lobes of *Oryctocephalops guizhouensis* are relatively shorter than the other two species. The pygidia of the latter two species are better defined from the thorax and with pygidial and thoracic spines about half the length of *Oryctocephalites taijiangensis*. The status of *Oryctocephalops ellipsoidalis* Zhao & Yuan *in* Yuan *et al.*, 2002, cannot be established due to only one specimen illustrated by Yuan *et al.* (2002, pl. 16, fig. 1) and the limited number of specimens of *O. guizhouensis* found during this study and illustrated by Yuan *et al.* (2002, pl. 15, figs 4–7, pl. 16, figs 2–7).

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX32, 36; Wuliu-Zengjiayan section, China.

Genus *Protoryctocephalus* Zhou (*in* Lu *et al.*, 1974b)

Type species. – *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al*., 1974b).

***Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al*., 1974b)**
Figure 13F–M

1974a *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*), p. 93, pl. 3, fig. 4.
1974b *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*, 1974b). – Zhou (*in* Lu *et al.*), p. 95, pl. 36, fig. 11.
1978 *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*, 1974b). – Zhou (*in* Yin & Lee), p. 440, pl. 156, fig. 1.
1980 *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*, 1974b). – Zhou (*in* Zhang *et al.*), p. 270, pl. 91, fig. 1.
1997 *Oryctocephalops* sp. *in* Yuan *et al.*, pl. 3, figs 1, 2.
2001 *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*, 1974b). – Yuan *et al.*, pl. 1, fig. 6.
2002 *Protoryctocephalus wuxunensis* Zhou (*in* Lu *et al.*, 1974b). – Yuan *et al.*, pp. 94, 95, 234, pl. 14, figs 1, 2.
2002 *Protoryctocephalus elongatus* Zhao & Yuan (*in* Yuan *et al.*), pp. 95, 96, 234, pl. 14, fig. 8, pl. 16, figs 8, 9.

Material. – 22 cranidia, 21 pygidia, 10 complete or partial shields.

Emended diagnosis. –*Protoryctocephalus* with cranidium with SO and S1 transglabellar furrow.

Remarks. – The biggest difficulty in the specific identification of this taxon is the compaction of the frontal lobe as the result of compression onto the hypostoma. *Protoryctocephalus wuxunensis* is probably the same species as *P. elongatus* Zhao & Yuan *in* Yuan *et al.*, 2002, with the latter being tectonically stretched (Fig. 13K, L vs. Fig. 13G). *Protoryctocephalus balangensis* Zhao & Yuan *in* Yuan *et al.*, 2002, differs from *P. wuxunensis* in having more than one transglabellar furrow. As with *O. indicus*, the number of furrows may be the result of tectonic distortion and compaction. In the samples studied here, most specimens have only one obvious transglabellar furrow. Only *P. balangensis* has been previously reported from the Wuliu-Zengjiayan section (Yuan *et al.* 2002). *Protoryctocephalus wuxunensis* has not been previously reported in faunal lists from either the Wuliu-Zengjiayan or Miaobanpo sections (Yuan *et al.* 2002).

Occurrence. – *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX29–32, 33–37, 39–41, 44–46, China.

***Protoryctocephalus balangensis* Zhao & Yuan (*in* Yuan *et al.*, 2002)**
Figure 13N

2002 *Protoryctocephalus balangensis* Zhao & Yuan (*in* Yuan *et al.*); pp. 94, 95, 234, pl. 14, figs 3–7, pl. 15, figs 1, 2.

Material. – 1 complete shield.

Remarks. – The specimen from FZX45 clearly show three transglabellar furrows and is assigned to this species.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry level FZX45; Wuliu-Zengjiayan and Miaobanpo sections, China.

Subfamily Oryctocarinae Hupé, 1953

Genus *Euarthricocephalus* Ju, 1983

Type species. – *Euarthricocephalus laterilobatus* Ju, 1983.

***Euarthricocephalus taijiangensis* Zhou & Yuan (*in* Yuan *et al.,* 2002)**
Figure 15F–L

1997 *Euarthricocephalus* sp. 1, Yuan *et al.*, pl. 3, figs 9, 10.
1999 *Microryctocara* sp., Sundberg *et al.*, pl. 1 fig. 2.
2001b *Microryctocara* sp., Zhao *et al.*, pl. 6, figs 5.
2002 *Euarthricocephalus* (*Euarthricocephalus*) *taijiangensis* Zhao & Yuan (*in* Yuan *et al.*); pp. 118, 248, pl. 33, figs 2, 3, pl. 34, figs 2–9, pl. 35, figs 2, 3.
2005a *Euarthricocephalus taijiangensis* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 6, fig. 5.

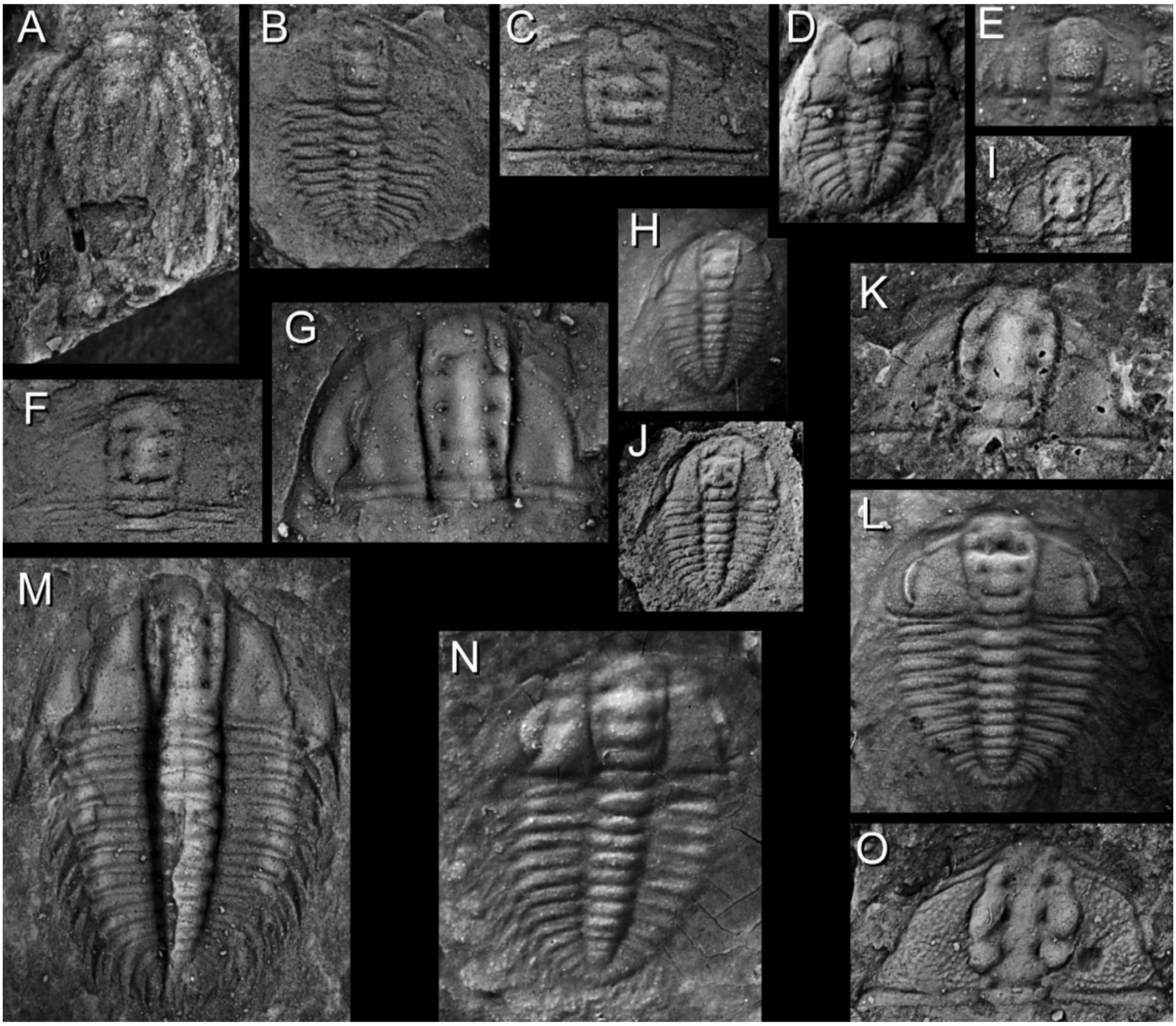


Figure 13. A – *Oryctocephalus elongates*? (Zhao, Alberg & Zhou, 1997), cranidium, calcite coated, GK B3 0070, × 8, FZX4. • B, C – *Oryctocephalops guizhouensis* Zhao & Yuan *in* Yuan *et al.*, 2002; B – partial shield, calcite coated, GK B3 0065, × 8, FZX36, C – cranidium, exfoliated, GK B3 0066, × 8, FZX32. • D, E – *Metabalangia yupingensis* Qian & Yuan *in* Zhang *et al.*, 1980; D – shield, exfoliated, GK B3 0072, × 10, FZX22, E – cranidium, not exfoliated, latex cast, GK B3 0071, × 12, FZX19. • F–M – *Protoryctocephalus wuxunensis* Zhou *in* Lu *et al.*, 1974b, all × 8. • F – cranidium with thoracic segment, exfoliated, GK B3 0073, FZX44. • G – cranidium and librigena, exfoliated, GK B3 0075, FZX44. • H, J – shield, not exfoliated, latex cast, GK B3 0077, FZX45; J – shield, exfoliated. • I – cranidium, exfoliated, GK B3 0078, FZX45. • K – cranidium, exfoliated, GK B3 0074, FZX30. • L – shield, not exfoliated, latex cast, GK B3 0076, FZX29. • M – shield, exfoliated, GK B3 0079, FZX44. • N – *Protoryctocephalus balangensis* Zhao & Yuan *in* Yuan *et al.*, 2002 shield, not exfoliated, latex cast, GK B3 0068, × 12, FZX45. • O – *Metarthricocephalus spinosus* Zhou & Yuan *in* Yuan *et al.*, 2002, cranidium, exfoliated, GK B3 0069, × 8, FZX8.

2005b *Euarthricocephalus taijiangensis* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 3, fig. 10.

Material. – 11 cranidia, 6 pygidia, 8 partial or complete shields.

Remarks. – *Euarthricocephalus taijiangensis* specimens are better preserved and more numerous than the similar *E. typicalis* Zhao & Yuan *in* Yuan *et al.*, 2002. The illustrated specimen of *E. typicalis* (Yuan *et al*. 2002, pl. 34, fig. 1) is distorted and relatively small and illustrates three transglabellar furrows and more slit shaped glabellar pits. The specimens of *E. taijiangensis* from the Wuliu Quarry do not have the slit shaped pits or three transglabellar furrows. In addition, *E. typicalis* occurs in the *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone in the Wuliu-Zengjiayan section (Yuan *et al.* 2002).

Euarthricocephalus (*Microryctocara*) *similis* Zhao & Yuan *in* Yuan *et al.*, 2002 and *Euarthricocephalus (Euarthricocephalus) ligulatus* Zhao & Yuan *in* Yuan

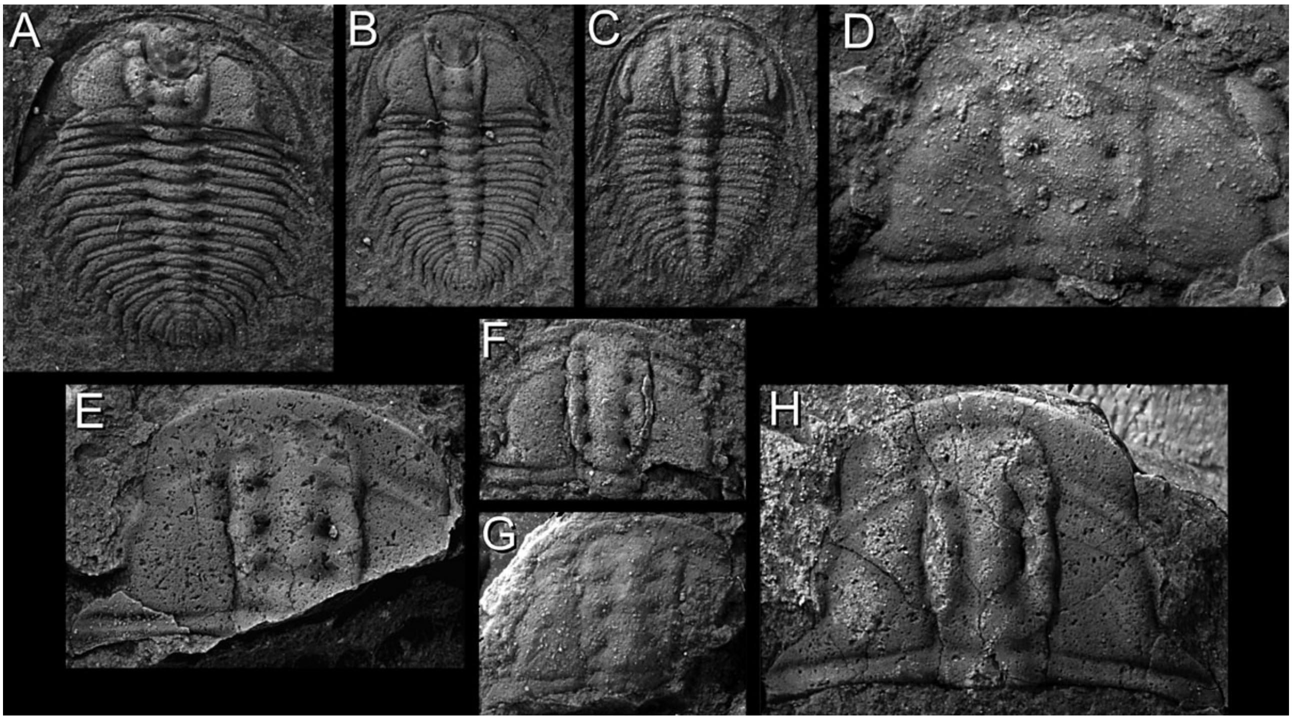


Figure 14. *Curvoryctocephalus taijiangensis* Zhao & Yuan *in* Yuan *et al.*, 2002, all figures × 7 unless otherwise noted. • A – complete shield, exfoliated, with hypostome impression, GK B3 0080, FZX12. • B, C – complete shield; B – exfoliated, with hypostome impression, GK B3 0081, C – not exfoliated, latex cast, GK B3 0082, FZX4. • D – cranidium, not exfoliated, latex cast, GK B3 0083, FZX3. • E – partial cranidium, mostly exfoliated, GK B3 0084, × 5, FZX17. • F – damaged cranidium, exfoliated, GK B3 0085, FZX1. • G – partial cranidium, exfoliated, GK B3 0086, FZX17. • H – cranidium, exfoliated, GK B3 0087, FZX21.

et al., 2002 differ from *E. taijiangensis* in having three transglabellar furrows and slit shaped glabellar pits.

Euarthricocephalus ligulatus has a more parallel sided glabella with stronger developed longitudal furrows and probably represents a different species. This species co-occurs in the same horizons as *E. taijiangensis* in the Miaobanpo section (Yuan *et al.* 2002).

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry levels FZX1–4, 7, 8, 11–14, 17, 18, 21; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Metabalangia* Qian & Yuan (*in* Zhang *et al.*, 1980)

Type species. – *Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*, 1980).

***Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*, 1980)**
Figure 13D, E

1980 *Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*); p. 283, pl. 96, figs 9, 10.

2002 *Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*, 1980). – Yuan *et al.,* pp. 127, 253, pl. 35, figs 4–8.

2002 *Metabalangia transversa* Zhao & Yuan (*in* Yuan *et al.*), pp. 128, 253, pl. 36, figs 1–12, pl. 38, figs 9, 10.

2005a *Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*, 1980). – Zhao *et al.*, pl. 7, fig. 1.

2005b *Metabalangia yupingensis* Qian & Yuan (*in* Zhang *et al.*, 1980). – Zhao *et al.*, pl. 3, fig. 6.

2010b *Oryctocephaloides convexus* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Sundberg *et al.*, fig. 1.

Material. – 2 cranidia, 1 complete shield.

Diagnosis. – See the emended generic diagnosis of Yuan *et al.* (2002, p. 252). The only two species named for the genus are here synonymized.

Remarks. – The poorly preserved complete shield has only 3 to 4 thoracic segments. *Metabalangia transversa* Zhao & Yuan *in* Yuan *et al.*, 2002 (Fig. 13D) is very similar to *M. yupingensis*, but differs in having 4 to 5 thoracic segments. The number of thoracic segments may be an ontogenetic change. The other differences cited by Yuan *et al.* (2002) do not appear to be consistent and may be the result of deformation. The two species occur together in the same horizons at the Wuliu-Zengjiayan and Miaobanpo sections (Yuan *et al.* 2002), suggesting that they are conspecific.

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry level FZX10, 19, 22; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Metarthricocephalus* Zhao & Yuan (*in* Yuan *et al.*, 2002)

Type species. – Metarthricocephalus spinosus Zhao & Yuan (*in* Yuan *et al.*, 2002).

***Metarthricocephalus spinosus* Zhao & Yuan (*in* Yuan *et al.*, 2002)**
Figure 13O

2001b Oryctocephalid *in* Zhao *et al.*, pl. 6, fig. 3.
2002 *Metarthricocephalus spinosus* Zhao & Yuan (*in* Yuan *et al.*); pp. 115, 246, pl. 28, fig. 1, pl. 29, fig. 8, pl. 32, figs 1–9, pl. 33, fig. 1.
2005a *Metarthricocephalus spinosus* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 6, fig. 3.
2005b *Metarthricocephalus spinosus* Zhao & Yuan (*in* Yuan *et al.*, 2002). – Zhao *et al.*, pl. 3, fig. 8.

Material. – 1 cranidium.

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry level FZX8; Wuliu-Zengjiayan and Jinyinshan sections, China.

Genus *Ovatoryctocara* Tchernysheva, 1962

Type species. – Oryctocara ovata Tchernysheva, 1960.

***Ovatoryctocara* cf. *granulata* Tchernysheva, 1962**
Figure 15A–E

1997 ?*Ovatoryctocara* spp. Yuan *et al.*, pl. 3, figs 11, 12.
2001a *Ovatoryctocara granulata* Tchernysheva, 1962. – Zhao *et al.*, pl. 1, figs 8, 9.
2001 *Ovatoryctocara granulata* Tchernysheva, 1962. – Yuan *et al.*, pl. 1, fig. 5.
2002 *Ovatoryctocara granulata* Tchernysheva, 1962. – Yuan *et al.*, pp. 125, 252, pl. 29, figs 4, 5.
2002 ?*Ovatoryctocara* sp. Yuan *et al.*, pp. 125, 252, pl. 31, figs 7, 8.
2002 *Ovatoryctocara* sp. Yuan *et al.*, pp. 125, 252, pl. 31, fig. 9.
2002 not *Ovatoryctocara granulata* Tchernysheva, 1962. – Yuan *et al.*, pp. 125, 252, pl. 31, figs 10–13 = *Ovatoryctocara yaxiensis* Yuan *et al.*, 2009.
2007 *Ovatoryctocara granulata* Tchernysheva, 1962. – Zhao *et al.*, fig. 4I.
2009 *Ovatoryctocara granulata* Tchernysheva, 1962. – Yuan *et al.*, p. 216, figs 2a, b, 3c.

Material. – 1 cranidium, 3 pygidia, 8 complete shields.

Remarks. – Some specimens previously reported as *Ovatoryctocara granulata* Tchernysheva, 1962 from the Kaili Formation (Yuan *et al*. 2001, 2002, 2009; Zhao *et al*. 2001a, 2007) differ from the type material (Naimark *et al*. 2011) in having a longer (exsag.) posterior area of the fixigena, shorter (exsag.) palpebral lobe placed more anteriorly, longitudinal glabellar furrows connecting the glabellar furrows, and a more prominent S3 transglabellar furrow. As a result, the specimens previously reported from the "*Ovatoryctocara granulata-Bathynotus holopygus* Zone" are assigned to *O.* cf. *granulata*.

Specimens of *Ovatoryctocara* spp. illustrated by Yuan *et al*. (1997, pl. 3, figs 11, 12; re-illustrated in Yuan *et al*. 2002, pl. 31, figs 7, 8) are either too poorly preserved or too small to accuately assign to *O*. cf. *granulata*. The specimen illustrated by Yuan *et al*. (2002, pl. 31, fig. 9) can be assigned to this species.

Ovatoryctocara yaxiensis Yuan *et al.*, 2009, from the Aoxi Formation differs from *O.* cf. *granulata* primarily in it more posterior placed palpebral lobes. The glabellar shape and presence of transglabellar furrows are also present in *O.* cf. *granulata* specimens from the Kaili Formation (Fig. 15C). *Ovatoryctocara* cf. *granulata* differs from O. *doliiformis* Shabanov & Korovnikov *in* Shabanov *et al.*, 2008b, in having smaller granuals on the cranidia, longitudinal furrows connecting the glabellar furrows, narrower (tr.) width of the librigena between the palpebral lobes and glabella, wider pygidial axis, and fewer pygidial segments.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX29, 31, 34, 36, 37, 42, 43, 45; Wuliu-Zengjiayan and Miaobanpo sections, China.

Order Ptychopariida Swinnerton, 1915
Superfamily Ptychoparioidae Matthew, 1887

Remarks. – Revision of the ptychopariid families is out of the scope of this paper, thus the species are listed alphabetically.

Genus *Balangcunaspis* Yuan & Zhao (*in* Yuan *et al.*, 1997)

Type species. – Paraantagmus (*Balangcunaspis*) *subcylindricus* Yuan & Zhao (*in* Yuan *et al.*, 1997).

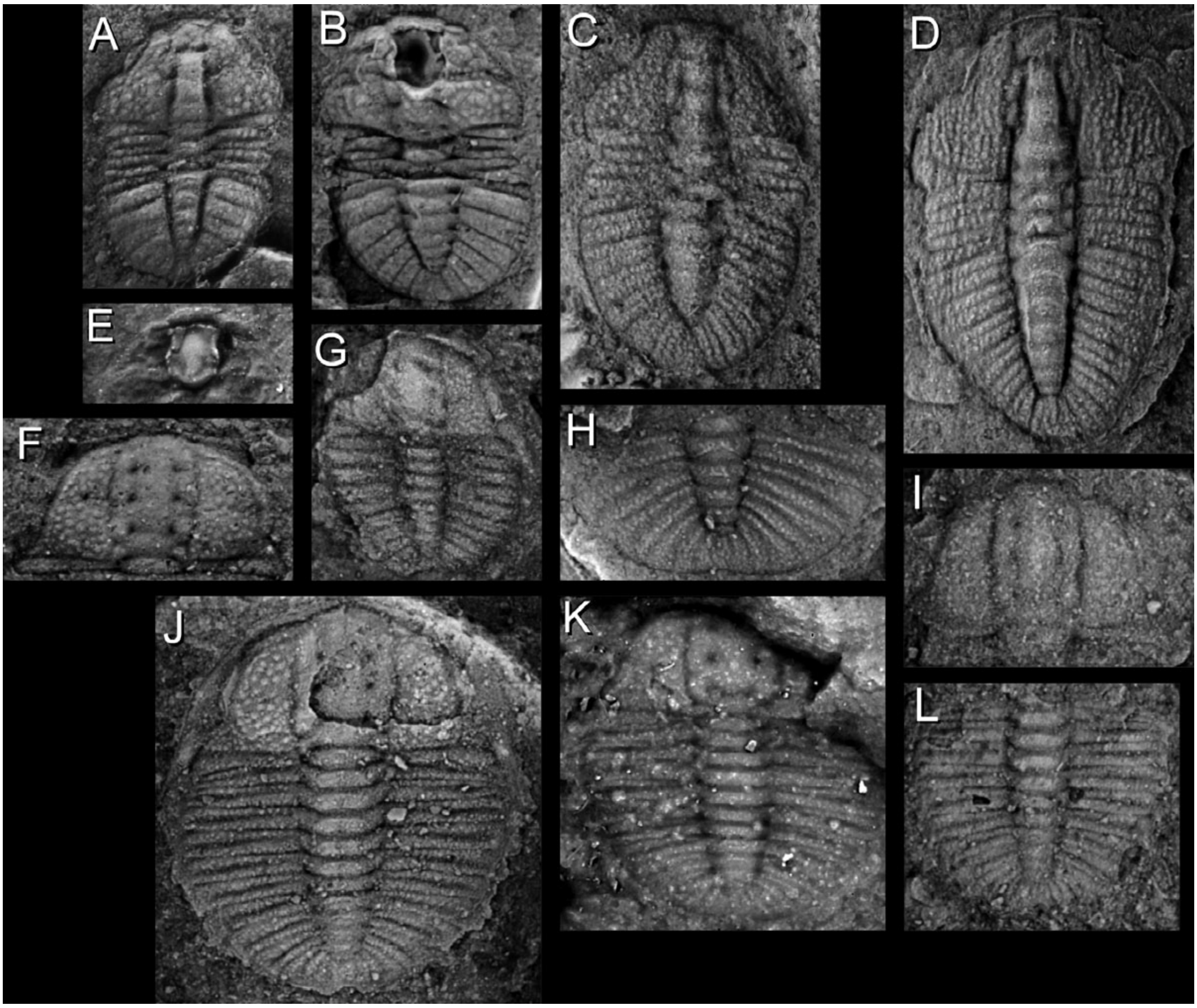


Figure 15. A–E – *Ovatoryctocara* cf. *granulata* Tchernysheva, 1962, all figures × 12. • A – partial shield, exfoliated, GK B3 0088, FZX29. • B, E – shield, exfoliated, GK B3 0089, FZX45; B – shield, exfoliated, E – hypostome, latex cast. • C – nearly complete shield, not exfoliated, latex cast, GK B3 0090, FZX34. • D – nearly complete shield, not exfoliated, latex cast, GK B3 0091, FZX42. • F–L – *Euarthricocephalus taijiangensis* Zhou & Yuan *in* Yuan *et al*., 2002, all figures × 12. • F – cranidium, exfoliated, GK B3 0092, FZX4. • G – partial shield, partially exfoliated, GK B3 0093, FZX18. • H – pygidium, exfoliated, GK B3 0094, FZX13. • I – cranidium, exfoliated, GK B3 0095, FZX4. • J – shield, partially exfoliated, GK B3 0096, FZX11. • K – partial shield, not exfoliated, latex cast GK B3 0097, FZX7. • L – thorax and pygidium, partially exfoliated, GK B3 0098, FZX17.

Remarks. – The two subgenera assigned to this genus by Yuan & Zhao (*in* Yuan *et al*. 1997, 2002), *Balangcunaspis* and *Taijiangia*, are distinctly different and should be considered different genera. *Balangcunaspis* has palpebral lobes that are longer, short (exsag.) posterior areas of the fixigena and pygidium with the anterolateral margins adjacent to the posterior end of the axis. *Taijiangia* Yuan & Zhao *in* Yuan *et al.*, 2002 (pp. 262, 263), has palpebral lobes that are shorter, a posterior area of the fixigena that is longer (exsag.), and the pygidial anterolateral margins adjacent to the anterior of the axis. *Balangcunaspis* is found in the *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone at the Wuliu-Zengjiayan section, where as *Taijiangia* is found in the basal beds of the overlying *Oryctocephalus indicus* Zone at the Miaobanpo section (Yuan *et al.* 2002).

***Balangcunaspis subcylindricus* Yuan & Zhao (*in* Yuan *et al.,* 1997)**
Figure 16A–P

1980 Protohedinidae gen. et sp. undet. Yuan (*in* Zhang *et al.*), p. 362, pl. 102, figs 10–12.

1997 *Paraantagmus* (*Balangcunaspis*) *subcylindricus* Yuan & Zhao (*in* Yuan *et al.*); p. 508, pl. 5, figs 6, 7.

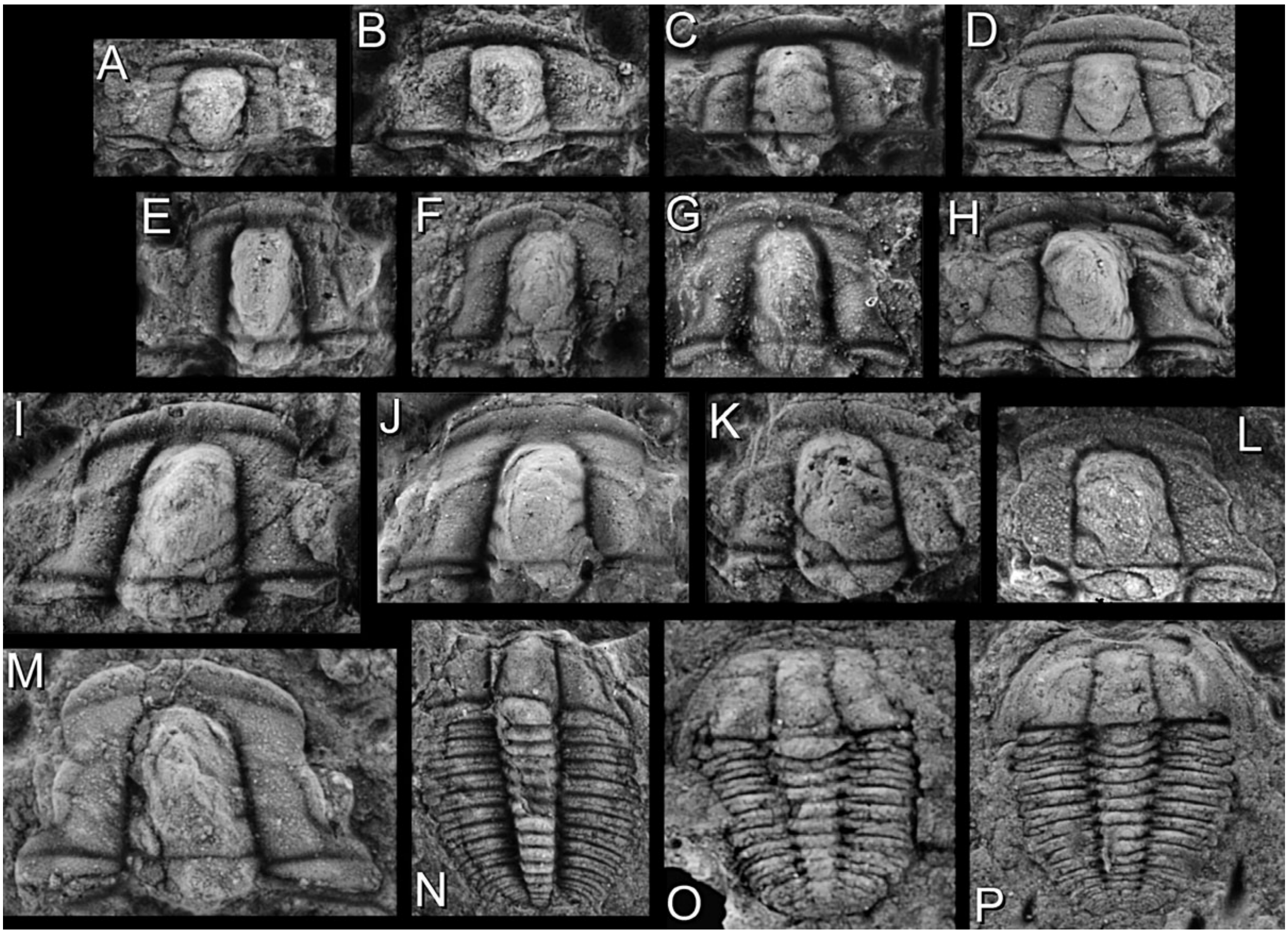


Figure 16. *Balangcunaspis subcylindricus* Yuan & Zhao *in* Yuan *et al*., 1997, all figures × 12. • A – partial cranidium, exfoliated, GK B3 0099, FZX40. • B – cranidium, exfoliated, GK B3 0100, FZX40. • C – partial cranidium, exfoliated, GK B3 0101, FZX29. • D – cranidium, exfoliated, GK B3 0102, FZX28. • E – cranidium, exfoliated, GK B3 0103, FZX40. • F – damaged cranidium, exfoliated, GK B3 0104, FZX45. • G – cranidium, not exfoliated, GK B3 0105, latex cast, FZX46. • H – cranidium, exfoliated, GK B3 0106, FZX34. • I – cranidium, exfoliated, GK B3 0107, FZX46. • J – cranidium, exfoliated, GK B3 0108, FZX30. • K – cranidium, exfoliated, GK B3 0109, FZX46. • L – partial cranidium, exfoliated, GK B3 0110, FZX44. • M – cranidium, exfoliated, GK B3 0111, FZX46. • N – partial shield, exfoliated, GK B3 0112, FZX34. • O – partial shield, exfoliated, GK B3 0113, FZX34. • P – partial shield, exfoliated, GK B3 0114, FZX46.

1997 *Balangcunaspis* (*Balangcunaspis*) *transversus* Yuan & Zhao (*in* Yuan *et al.*), p. 508, pl. 5, figs 4, 5.

1999 *Balangcunaspis transversus* Yuan & Zhao (*in* Yuan *et al.,* 1997). – Yuan *et al*., p. 27, pl. 1, fig. 1.

2002 *Balangcunaspis (Balangcunaspis) subcylindricus* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Yuan *et al.*, pp. 148, 149, 262, pl. 43, figs 7–12.

2002 *Balangcunaspis (Balangcunaspis) transversus* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Yuan *et al.*, pp. 149, 262, pl. 43, figs 1–6.

2010b *Balangcunaspis transversus* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Sundberg *et al*., fig. 1.

Material. – 147 cranidia, 14 pygidia, 8 partial or complete shields.

Emended diagnosis. – Balangcunaspis with palpebral lobes nearly one and a half as long as posterior area of the fixigena (150%); ocular ridges directed moderately posterio-laterally, of moderate strength; glabellar length approximately 80–85% of cranidial length; preglabellar field length nearly absent in front of glabella; anterior border slightly convex, flat to upturned; facial sutures slightly divergent anterior of palpebral lobes, very strongly divergent (approx. 90°) from the posterior end of the palpebral lobes.

Remarks. – The difference between *B. subcylindricus* and *B. transversus* Yuan & Zhao *in* Yuan *et al.*, 1997, can easily be explained due to specimen distortion. *Balangcunaspis subcylindricus* is sagittally elongated (*e.g*., Fig. 16E–G) whereas *B. transversus* is transversely elongated (*e.g.*, Fig. 16B–D). Both species have been reported to occur together in the Wuliu-Zengjiayan section (Yuan *et al.* 2002).

Cranidia with a relatively small frontal area (Fig. 16J, L, M) and at times almost no preglabellar field (Fig. 16I, K) and long palpebral lobes belong only to a limited number of genera from the Kaili Formation, *i.e.*, *Balangcunaspis* Yuan & Zhao *in* Yuan *et al.*, 1997, *Nangaoia* Zhou *in* Lu *et al.*, 1974a, and *Parashuiyuella* Yuan & Zhao *in* Yuan *et al.*, 1997. In both *Nangaoia* and *Parashuiyuella* the fixigena at the center of the palpebral lobes is less than half the width of the glabella at the position, where as *Balangcunaspis* has the width nearly equal or slightly greater than half of the width of the glabella. The glabella of *Balangcunaspis* is more quadrate than tapered, although this is a dangerous character to use based on the specimen distortion. *Balangcunaspis subcylindricus* is represented by mostly small specimens.

Both *B. subcylindricus* and *B. transverses* have been recorded only from in the *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* by Zhao *et al.* (2005a, p. 66); but also from the *Oryctocephalus indicus* Zone by Zhao *et al*. (2007, fig. 1).

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX26–36, 38–46; *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* and *Oryctocephalus indicus* zones: Wuliu-Zengjiayan section, China.

Genus *Danzhaiaspis* Yuan & Zhou (*in* Zhang *et al.*, 1980)

Type species. – *Danzhaiaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*, 1980).

Danzhaiaspis quadratus Yuan & Zhou (*in* Zhang *et al.*, 1980)

Figure 17A–O

1980 *Danzhaiaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*); pp. 355, 356, pl. 125, figs 1–5.
1980 *Danzhaiaspis latilimbatus* Yuan (*in* Zhang *et al.*), p. 356, pl. 125, fig. 6.
1980 *Danzhaiaspis brevicus* Yuan (*in* Zhang *et al.*), pp. 356, 357, pl. 125, fig. 7–9.
1980 *Danzhaiaspis niuchangensis* Zhou (*in* Zhang *et al.*), p. 357, pl. 124, fig. 6.
1980 *Danzhaiaspis*? *sanwanensis* Yuan (*in* Zhang *et al.*), pp. 357, 358, pl. 125, fig. 10, 11.
1999 *Danzhaiaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pl. 1, fig. 8.
2002 *Danzhaiaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 202, 281, pl. 64, figs 1–8, pl. 67, figs 7–9.
2002 *Danzhaiaspis elongatus* Yuan & Zhao (*in* Yuan *et al.*), pp. 202, 203, 281, pl. 54, figs 11, pl. 61, figs 3–8, pl. 65, fig. 10, pl. 67, fig. 3.
2002 *Danzhaiaspis brevis* Yuan (*in* Zhang *et al.*), pp. 203, 204, 281, pl. 64, fig. 4.
2002 *Danzhaiaspis rarus* Yuan & Zhao (*in* Yuan *et al.*), pp. 204, 281, 282, pl. 61, fig. 9.
2010b *Kutsingocephalus qiannanensis* Yuan & Zhou (*in* Yuan *et al*., 2002). – Sundberg *et al*., fig. 1.
not 2010b *Danzhaiaspis quadratus* Yuan & Zhou (*in* Zhang *et al*., 1980). – Sundberg *et al*., fig. 1 = *Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980).

Material. – 57 cranidia, 3 pygidia, 4 partial or complete shields.

Emended diagnosis. – Danzhaiaspis with the palpebral lobes longer than the posterior portion of the fixigena (150%); ocular ridges slightly to moderately directed posterio-laterally; glabellar length approximately 65–70% of cranidial length; fixigena narrower than glabella at center of palpebral lobes; anterior border approximately 100% of preglabellar field, flat to very slightly convex, slightly to moderately upturned; facial sutures moderately divergent anterior of palpebral lobes, strongly divergent (approx. 90°) from the posterior end of palpebral lobes. Pygidium transversely elongated with anterior lateral corners located adjacent to nearly the end of the axis, and well developed border widening laterally. Fine granules on the glabella and librigena occur on the latex casts of the better-preserved specimens (Fig. 17F, K).

Remarks. – This species is difficult to identify due to its general cranidial characteristics similar to *Xingrenaspis xingrenensis*. *Danzhaiaspis quadratus* differs in the length ratio of the preglabellar area and the anterior border being nearly equal as opposed to the preglabellar area being twice as long; the anterior border is upturned to level, possibly as the result of compaction; and the palpebral lobe length is nearly 150% the length of the posterior area of the fixigena.

The differences of the various species included to *D. quadratus* are relatively minor and can be contributed to tectonic distortion. In addition, stratigraphic evidence supporting the synonymy of *D. quadratus* and *D. elongatus* Yuan & Zhao *in* Yuan *et al*., 2002, is that the two species occur together in the Miaobanpo section (Yuan *et al.* 2002). In the Wuliu-Zengjiayan section, the different species occur at different levels, one directly above the other in the ascending order of *D. quadratus*, *D. brevis* Yuan *in* Zhang *et al*., 1980, *D. elongatus* and *D. rarus* Yuan & Zhao *in* Yuan *et al*., 2002 (Yuan *et al.* 2002).

The cranidia of this species is very similar to compressed specimens of *M. angustilimbata*, but differs in a more latterly projected ocular ridge, which is difficult to determine in the deformed specimens from the quarry. The

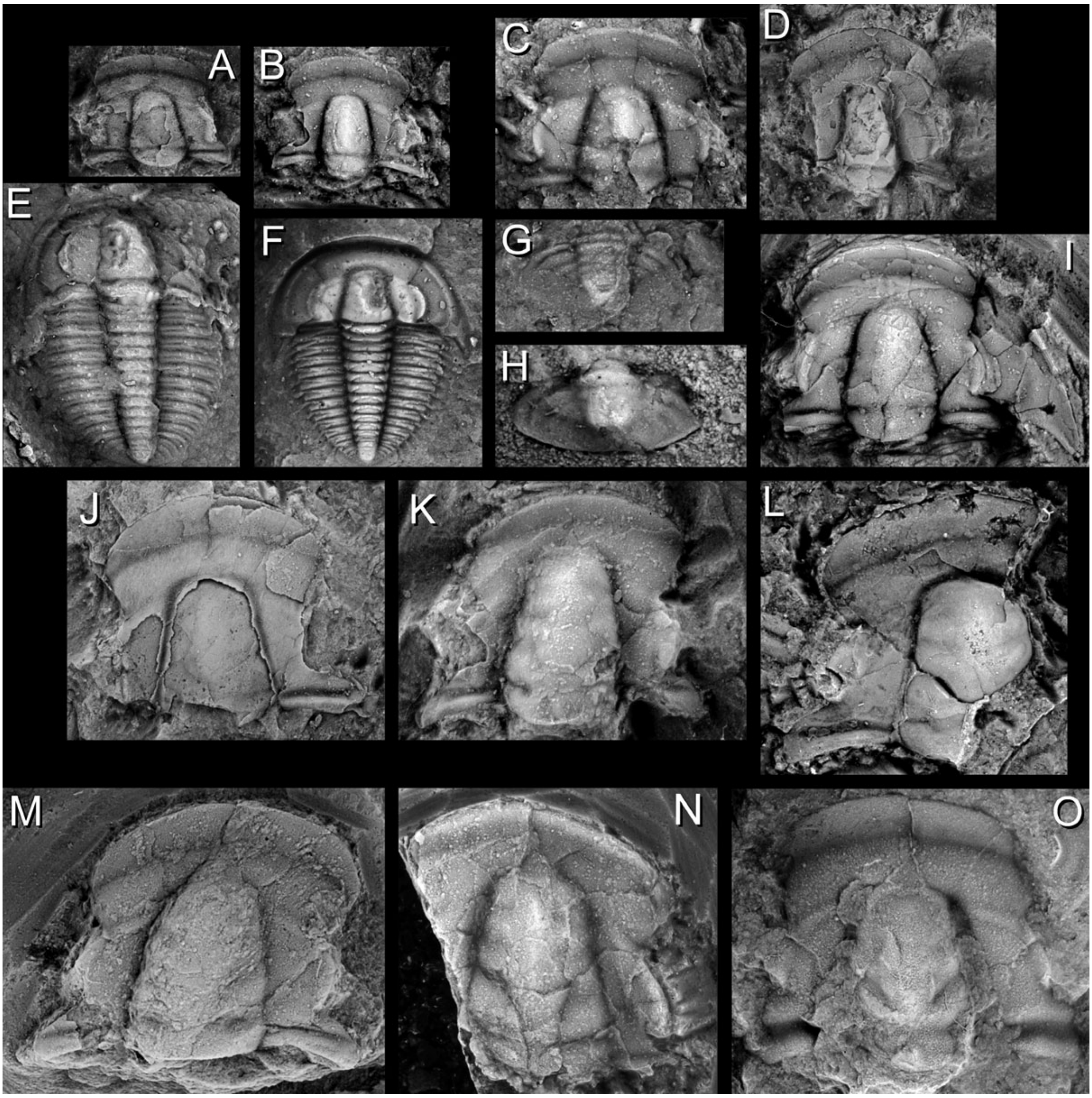


Figure 17. *Danzhaiaspis quadratus* Yuan & Zhou *in* Zhang *et al*., 1980, all figures × 5, unless otherwise noted. • A – cranidium, partially exfoliated, GK B3 0115, FZX17. • B – cranidium, not exfoliated, GK B3 0116, FZX4. • C – cranidium, not exfoliated, latex cast, GK B3 0117, FZX15. • D – cranidium, mostly exfoliated GK B3 0118, FZX24. • E – partial shield, not exfoliated, GK B3 0120, latex cast, FZX6. • F – shield, exfoliated, GK B3 0121, FZX20. • G – pygidium, partially exfoliated, latex cast, GK B3 0122, FZX20. • H – pygidium, not exfoliated, latex cast, GK B3 0123, FZX9. • I – cranidium and librigena, partially exfoliated, GK B3 0124, FZX3. • J – partial cranidium, partially exfoliated, GK B3 0119, FZX13. • K – mostly complete cranidium, not exfoliated, GK B3 0128, FZX1. • L – partial, crushed cranidium, exfoliated, GK B3 0127, FZX9. • M – cranidium, not exfoliated, GK B3 0128, FZX24. • N – partial cranidium, not exfoliated, GK B3 0129, FZX12, × 4. • O – cranidium, not exfoliated, GK B3 0125, latex cast, FZX20.

pygidium is the most diagnostic character to distinguish the two species. *Danzhaiaspis quadratus* has a wide relatively flat pygidial margin that widens significantly laterally and a similar doublure. A shield from FZX20 (Fig. 17F) has a pygidium that indicates that this specimen is *Danzhaiaspis quadratus* and not *M. angustilimbata* even though the cranidia are very similar. This indicates the importance of having associated sclerites in addition to cranidia.

Occurrence. – Kaili Formation, *Oryctocephalus indicus*

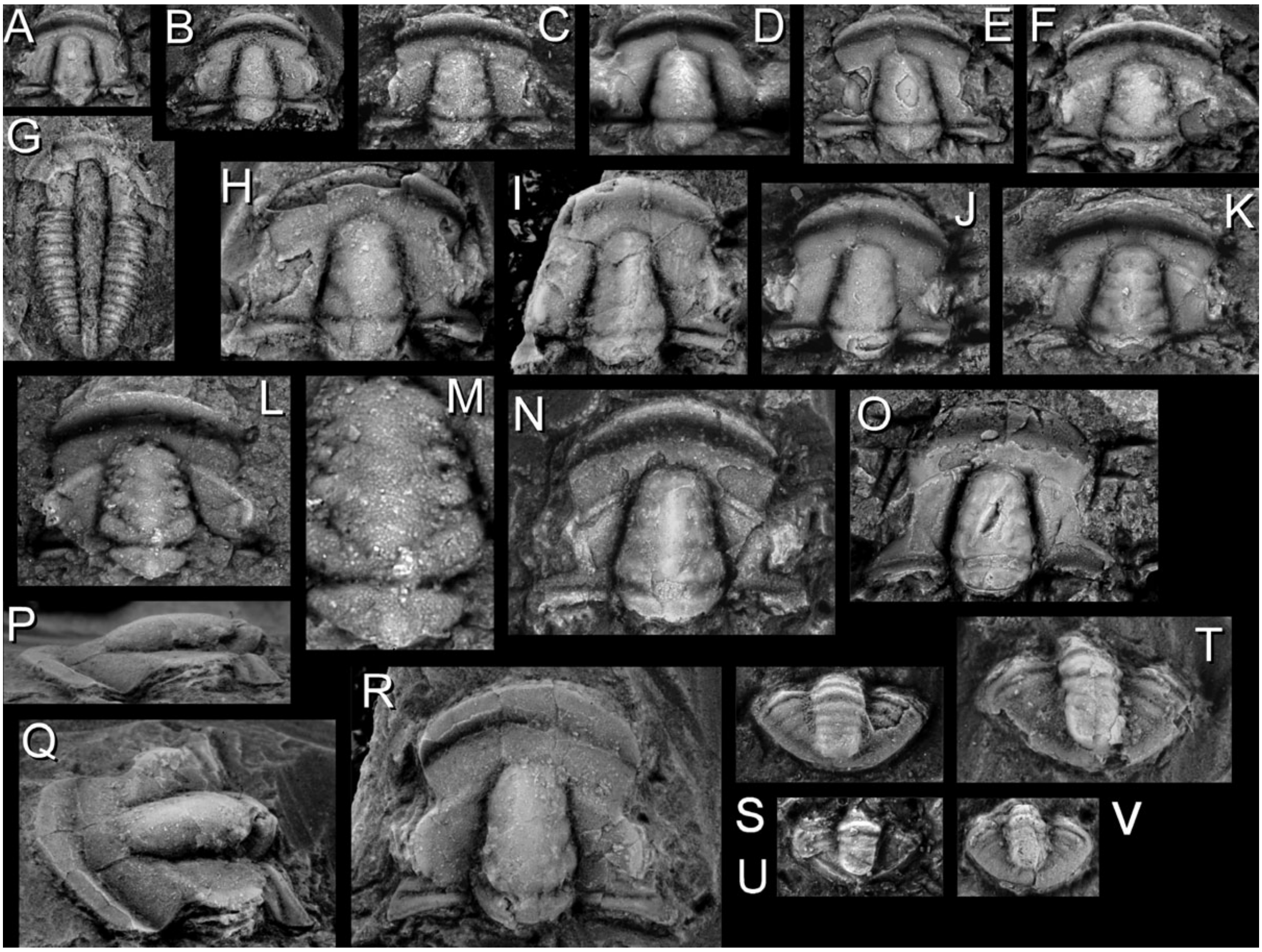


Figure 18. *Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980), all figures × 5 unless otherwise noted. • A – cranidium, not exfoliated, GK B3 0130, FZX9. • B – cranidium, not exfoliated, GK B3 0131, FZX11. • C – cranidium, not exfoliated, GK B3 0132, FZX13. • D – cranidium, not exfoliated, GK B3 0133, latex cast, FZX13. • E – partial cranidium, not exfoliated, GK B3 0134, FZX13. • F – cranidium, not exfoliated, GK B3 0135, FZX11. • G – shield, poorly preserved internal mold illustrating pygidium, GK B3 0136, FZX21. • H – cranidium, partially exfoliated, GK B3 0137, FZX12. • I – partially crushed cranidium, not exfoliated, GK B3 0138, FZX24. • J – cranidium, not exfoliated, GK B3 0139, FZX13. • K – cranidium, not exfoliated, GK B3 0140, FZX9. • L, M – cranidium, partially exfoliated, GK B3 0141, latex cast, fig. M showing granular ornamentation, × 10, FZX9. • N – cranidium, partially exfoliated, GK B3 0142, FZX11. • O – damaged cranidium, partially exfoliated, GK B3 0143, FZX9. • P–R – cranidium with crushed anterior border, not exfoliated, GK B3 0164, FZX24. • S – pygidium, partially exfoliated, GK B3 0145, FZX9. • T – damaged pygidium, not exfoliated, GK B3 0146, FZX9. • U – damaged pygidium, not exfoliated, GK B3 0147, latex cast, FZX9. • V – pygidium, not exfoliated, GK B3 0148, FZX14.

Zone: Wuliu Quarry levels FZX1–6, 9–17, 19–22, 24, 25; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Miabanpoia* Yuan & Zhao (*in* Yuan *et al.*, 2002)

Type species. – *Miabanpoia typica* Yuan & Zhao (*in* Yuan *et al.*, 2002) [= *Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980)].

Remarks. – The differences between *M. typica, M. triangulata* Yuan & Zhao *in* Yuan *et al.,* 2002, and *M. angustilimbata* are minor and could easily be due to tectonic distortion; the three specimens occur together in the Miaobanpo section. *Miabanpoia angustilimbata* has priority.

***Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980)**
Figure 18A–V

1980 *Meitania angustilimbata* Yuan (*in* Zhang *et al.*); p. 349, pl. 119, figs 21, 22.

2002 *Danzhaiaspis brevis* Yuan (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 203, 204, 281, 282, pl. 62, fig. 4.

2002 *Miabanpoia typica* Yuan & Zhao (*in* Yuan *et al.*), pp. 205, 283, pl. 68, fig. 7.

2002 *Miabanpoia angustilimbata* (Yuan *in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 205, 206, 283, pl. 66, figs 1–4.
2002 *Miabanpoia triangulata* Yuan & Zhao (*in* Yuan *et al.*), pp. 206, 207, 283, pl. 63, fig. 11, pl. 65, figs 5–7, pl. 66, figs 5–10, pl. 67, figs 5, 6, pl. 68, figs 2–6.
2010b *Danzhalaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*, 1980). – Sundberg *et al.*, fig. 1.

Material. – 348 cranidia, 6 pygidia, 5 partial or complete shields.

Emended diagnosis. – *Miabanpoia* with palpebral lobes nearly twice to twice as long as the posterior area of the fixigena (180–200%); ocular ridges moderately strong posterio-laterally; glabellar length approximately 68–73% of cranidial length; anterior border approximately 100–150% of preglabellar field; anterior border slightly convex to flat (could be influenced by compaction), strongly upturned, slightly tapering laterally; facial sutures moderately divergent anterior of palpebral lobes, very strongly divergent (approx. 90°) from the posterior end of palpebral lobes. Pygidium transversely elongated with anterior lateral corners located about the mid-length of the pygidium; doublure narrow at posterior margin, nearly uniform to the anterior margin; pleural furrows prominent, interpleural furrows moderately developed; axis with 4 rings, width about ½ pleural field width, rounded terminal piece that nearly reaches the posterior border. Granular exoskeleton is present in latex casts (Fig. 18M).

Remarks. – The strongly upturned anterior border is one of the most distinct features of this species, along with the palpebral lobes being nearly twice as long as the posterior area of the fixigena. The difference in the pygidium is the nearly uniform width of the pygidial border and the underlying doublure. Many of the pygidia illustrated by Yuan *et al.* (2002) appear to have wider borders.

Yuan *et al.* (2002) assigned a single pygidium to *Meitania suni* (Lu, 1945) illustrated in Zhang *et al.* (1980, pl. 119, fig. 15) to *M. angustilimbata*; however, this pygidium is not well enough preserved to determine its taxonomic affinity. A moderately preserved specimen of *Danzhaiaspis brevis* Yuan *in* Zhang *et al.*, 1980, illustrated in Yuan *et al.* (2002, pl. 62, fig. 4) has a cranidium and pygidium very similar to *M. angustilimbata* and is thus considered a specimen belonging to the latter species. Specimens illustrated by Yuan (*in* Zhang *et al.* 1980) of *D. brevis* and *D.* ?*xingrenensis* Yuan & Zhou *in* Zhang *et al.*, 1980, are not assigned to *M. angustilimbata*, but rather *Danzhaiaspis quadratus*.

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry levels FZX1–25; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Nangaoia* Zhou (*in* Lu *et al.*, 1974a)

Type species. – *Nangaoia megaceps* Zhou (*in* Lu *et al.*, 1974a).

Remarks. – Three subgenera have been recognized in *Nangaoia* (Yuan *et al.* 1997), *Nangaoia*, *Shilengshuia* Zhou & Yin *in* Yin *et al.*, 1978, and *Gedongaspis* Yuan & Zhao *in* Yuan *et al.*, 1997. Yuan *et al.* (2002, p. 263) elevated *Gedongaspis* to generic level. *Gedongaspis granulosa* Yuan & Zhao *in* Yuan *et al.*, 1997 (type species) and *G. oblonga* Yuan & Zhao *in* Yuan *et al.*, 1997, occur together (Yuan *et al.* 2002) implies one species with a variation in the density of granules. However, the pygidia of the two species are different in the strength of the interplural furrows, border width and location of the anterior lateral corners relative to the axis. *Nangaoia* (*Nangaoia*) *triangularis* Yuan & Zhao *in* Yuan *et al.*, 2002 (pl. 42, figs 3, 4), have a pygidium similar to *Xingrenaspis* with a wide border narrowing posterior of the axis. The post cranidial material of *Nangaoia* (*Shilengshuia*) is unknown, thus a comparison cannot be made; however, the cranidial features of this subgenus differs from *N.* (*Nangaoia*) in having a more tapered glabella, narrower (tr.) fixigena and convergent anterior branches of the facial sutures. However, *N.* (*N.*) *triangularis* (Yuan *et al.* 2002, pl. 42, fig. 2) illustrates the same features, but with wider fixigena.

Subgenus *Nangaoia* (*Shilengshuia*) Zhou & Yin (*in* Yin & Lee, 1978)

Type species. – *Shilengshuia jiubaensis* Zhou & Yin (*in* Yin & Lee, 1978).

***Nangaoia* (*Shilengshuia*) *conica* Yuan & Zhao (*in* Yuan *et al.*, 2002)**
Figure 19A–I, J?

2002 ?*Nangaoia* (*Nangaoia*) *triangularis* Yuan & Zhao (*in* Yuan *et al.*); pp. 146, 147, 260, pl. 42, figs 2–4.
2002 *Nangaoia* (*Shilengshuia*) *conica* Yuan & Zhao (*in* Yuan *et al.*), pp. 147, 261, pl. 42, figs 5, 6, 8–10.
2010b *Gedongaspis granulosa* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Sundberg *et al.*, fig. 1.
2010b *Nangaoia triangularis* Yuan & Zhao (*in* Yuan *et al.*, 2002). – Sundberg *et al.*, fig. 1.

Material. – 35 cranidia.

Emended diagnosis. – *Nangaoia* with relatively large glabella extending nearly to the anterior border, palpebral lobes of moderate length, narrow fixigenae, scattered

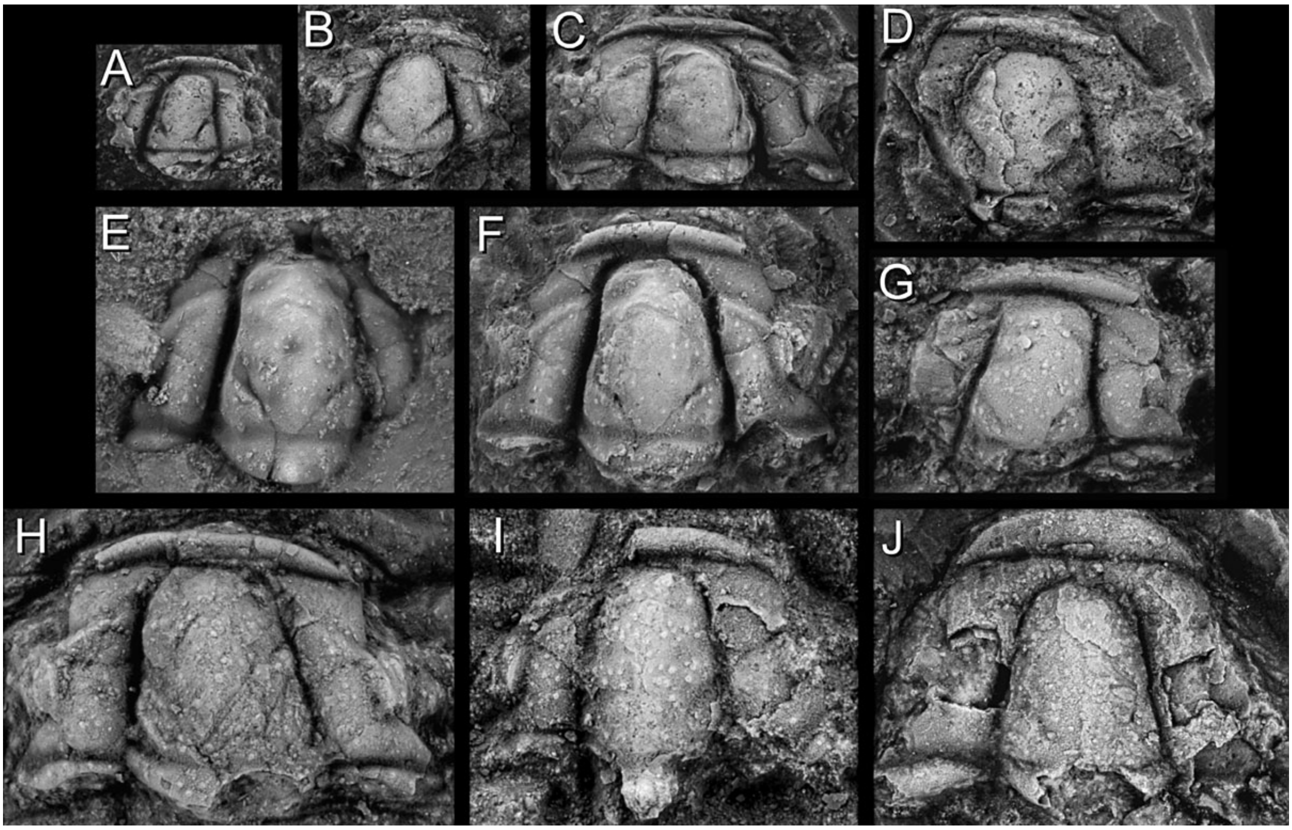


Figure 19. A–I, J? – *Nangaoia* (*Shilengshuia*) *conica* Yuan & Zhao *in* Yuan *et al*., 2002, all figures × 7 unless otherwise noted. • A – cranidium, partially exfoliated, GK B3 0149, FZX18. • B – damaged cranidium, partially exfoliated, GK B3 0150, FZX22. • C – cranidium, mostly exfoliated, GK B3 0151, FZX8. • D – damaged cranidium, partially exfoliated, GK B3 0152, FZX7. • E – partial cranidium showing occipital node, exfoliated, GK B3 0153, latex cast, FZX8. • F – cranidium, exfoliated, GK B3 0154, FZX8. • G – cranidium, partially exfoliated, GK B3 0155, FZX4. • H – cranidium, not exfoliated, GK B3 0156, FZX19. • I – partial cranidium, partially exfoliated, GK B3 0157, FZX16. • J – cranidium questionably assigned to the species, partially exfoliated, GK B3 0158, FZX9, × 3.

granules on the cranidia, and anterior border that is convex, upturned and slightly curved.

Remarks. – *Nangaoia* (*S.*) *conica* and *N.* (*N.*) *triangularis in* Yuan *et al.*, 2002 (pl. 42) appears to be quite different, especially in the curvature of the anterior border and the tapering of the glabella. However, it is unsure if the *N.* (*N.*) *triangularis* form may be more the result of tectonic deformation given that almost all specimens looked laterally compressed. It is possible that *N.* (*S.*) *conica* in pl. 42, fig. 8 (Yuan *et al.* 2002) could be a highly distorted specimen of *N.* (*N.*) *triangularis.* The specimens of *N.* (*N.*) *triangularis* are questionably assigned to *N.* (*S.*) *conica* until more data on the two taxa can be accumulated to show that they are different taxa.

A single large specimen (Fig. 19J, level FZX9) illustrates a more tapered glabella, presence of a preglabellar area, more convergent anterior portion of the facial suture, and an anterior border that is longer (sag.) and more tapered than in the other specimens. However, these features are also present in some specimens of *N.* (*S.*) *conica* (Yuan *et al.* 2002, pl. 42, figs 8, 10). This larger specimen is questionably assigned to the species.

Occurrence. – Kaili Formation, *Oryctocephalus indicus* Zone: Wuliu Quarry levels FZX1, 3, 4, 7, 8, 10, 13–16, 18–22, 28, 29; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Nangaops* Yuan & Sun (*in* Zhang *et al.,* 1980)

Type species. – *Nangaops elongatus* Yuan & Sun (*in* Zhang *et al.*, 1980), "Middle" Cambrian, Chongyang, Hubei, China; [= to *Elrathina danzhaiensis* Zhou (*in* Lu *et al.*, 1974a)].

Remarks. – According to Yuan *et al.* (2002), the genus was originally named in a manuscript Yuan & Sun (M.S. 1978). However, the first published description of *Nangaops* is in Zhang *et al.* (1980, pp. 317, 436). If the synonymy presented below is correct, *N. elongatus* is a junior synonym of *N. danzhaiensis*.

Nangaops danzhaiensis **(Zhou *in* Lu *et al.*, 1974a)**
Figure 20A–X

1974a *Elrathina danzhaiensis* Zhou (*in* Lu *et al.*); p. 99, pl. 38, fig. 11.
1978 *Nangaops danzhaiensis* (Zhou *in* Lu *et al.*, 1974a). – Zhou (*in* Yin & Lee), p. 471, pl. 162, fig. 12.
1980 *Nangaops elongatus* Yuan & Sun (*in* Zhang *et al.*), pp. 317, 318, fig. 88, pl. 106, figs 1–3.
1980 *Nangaops latilimbatus* Yuan (*in* Zhang *et al.*), p. 318, pl. 106, figs 4–6.
1980 *Nangaops danzhaiensis* (Zhou *in* Lu *et al.*, 1974a). – Yuan (*in* Zhang *et al.*), pp. 318, 319, pl. 106, fig. 7.
1980 *Nangaops brevicus* Yuan & Sun (*in* Zhang *et al.*), p. 319, fig. 89, pl. 106, figs 8–11.
1980 *Nangaops rara* Yuan (*in* Zhang *et al.*), pp. 319, 320, pl. 106, fig. 12.
1980 *Nangaops nangaoensis* Yuan (*in* Zhang *et al.*), p. 320, pl. 106, figs 13–17.
1983 *Nangaops yuhangensis* Ju, p. 84, pl. 27, fig. 3.
1984 *Nangaops elongatus* Yuan & Sun (*in* Zhang *et al.*, 1980). – Sun, pp. 354, 355, pl. 134, figs 1, 2.
1984 *Nangaops brevicus* Yuan & Sun (*in* Zhang *et al.*, 1980). – Sun, p. 355, pl. 133, figs 7, 8, pl. 134, figs 3, 4.
1984 *Nangaops danzhaiensis* (Zhou *in* Lu *et al.*, 1974a). – Sun, p. 355, pl. 134, figs 5, 6.
1997 *Nangaops brevicus* Yuan & Sun (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pl. 5, fig. 13.
1999 *Nangaops elongatus* Yuan & Sun (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pl. 1, fig. 2.
2002 *Nangaops elongatus* Yuan & Sun (*in* Zhang *et al.*, 1980). – Yuan *et al.*, p. 193, pl. 60, figs 9–11.
2002 *Nangaops brevis* Yuan & Sun (*in* Zhang *et al.*, 1980). – Yuan *et al.*, p. 194, pl. 60, figs 2–4, 6–8.
2002 *Nangaops danzhaiensis* (Zhou *in* Lu *et al.*, 1974a). – Yuan *et al.*, p. 194, pl. 60, figs 1, 5.
2010a *Nangaops brevis* Yuan & Sun (*in* Zhang *et al.*, 1980). – Sundberg *et al.*, p. 24.
2010b *Nangaops brevis* Yuan & Sun (*in* Zhang *et al.*, 1980). – Sundberg *et al.*, fig. 1.
2010b *Eosoptychoparia conica* Yuan (*in* Zhang *et al.*, 1980). – Sundberg *et al.*, fig. 1.

Material. – 130 cranidia, 36 pygidia, 11 partial or complete shields.

Emended diagnosis. – Nangaops with short palpebral lobes; ocular ridges that project at nearly 90° from the glabella; posterior portion of the fixigena exsagittally long; preglabellar area about 25% of cranidial length; convergent anterior branches of the facial sutures, divergent posterior branches of the facial sutures at nearly 45°; and anterior border relatively short (sag.) and slightly convex.

Remarks. – The type specimens of *Nangaops elongatus*, type species, are clearly tectonically distorted, being elongated sagittally. The distortion of the specimens from the Wuliu Quarry falls within the range of the previously named species of *Nangaops*. *Nangaops brevis* is transversely elongated, *N. danzhaiensis* appears to have proper dimensions, *N. nangaoensis* has been sagittally elongated and *N. rara* Yuan *in* Zhang *et al.*, 1980, and *N. latilimbatus* are similar to *N. brevis*. Whereas most of the species have a tapering glabella, *N. elongatus* has a more parallel sided glabella; this again can be the result of the tectonic stretching. In addition, Zhao *et al.* (2001a, fig. 4; 2005a, fig. 7) list *N. brevicus* (= *N. brevis*), *N. danzhaiensis*, *N. latilimbatus*, and/or *N. nangaoensis* from the same horizons within 3 meters below the FAD of *Oryctocephalus indicus*. These co-occurrences suggest that the different species are just different tectonic distortions and/or morphological variations of a single species.

Sundberg *et al.* (2010a, b) assigned several specimens of *N. danzhaiensis* (listed as *N. brevis*) to *Eosoptychoparia conica* Yuan (*in* Zhang *et al.,* 1980), because of the elongated cranidia and more parallel-sided glabella. However, based on the anterior border, convergent anterior facial sutures, short palpebral lobes, and lack of a pygidium similar to *E. conica*, these specimens are regarded here in as sagittally elongated specimens of *N. danzhaiensis*. These specimens were also found in the same horizons as *N. danzhaiensis*.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX29–46; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Probowmania* Kobayashi, 1935

Type species. – Ptychoparia ligea Walcott, 1905.

Remarks. – Yuan *et al.* (1997, 2002) placed three genera into subernera of *Probowmania*, *Probowmania*, *Mufushania* Lin, 1965, and *Gunnia* Gatehouse, 1968. Peng *et al.* (2009, pp. 49, 59) discussed the subgenera *Gunnia* and *Mufushania* and re-elevated them to generic rank. The differences between *Probowmania* and *Mufushania* listed by Peng *et al*. (2001) are inconsistent in the samples from the Wuliu Quarry and those illustrated by Yuan *et al*. (1997, 2002). Thus *Probowmania* is retained and *Mufushania* is considered a junior synonym.

Probowmania nankingensis **Lin, 1965**
Figure 21A–T

1965 *Probowmania* (*Mufushania*) *nankingensis* Lin; pp. 554, 555, 558, 559, pl. 1, fig. 6–11.

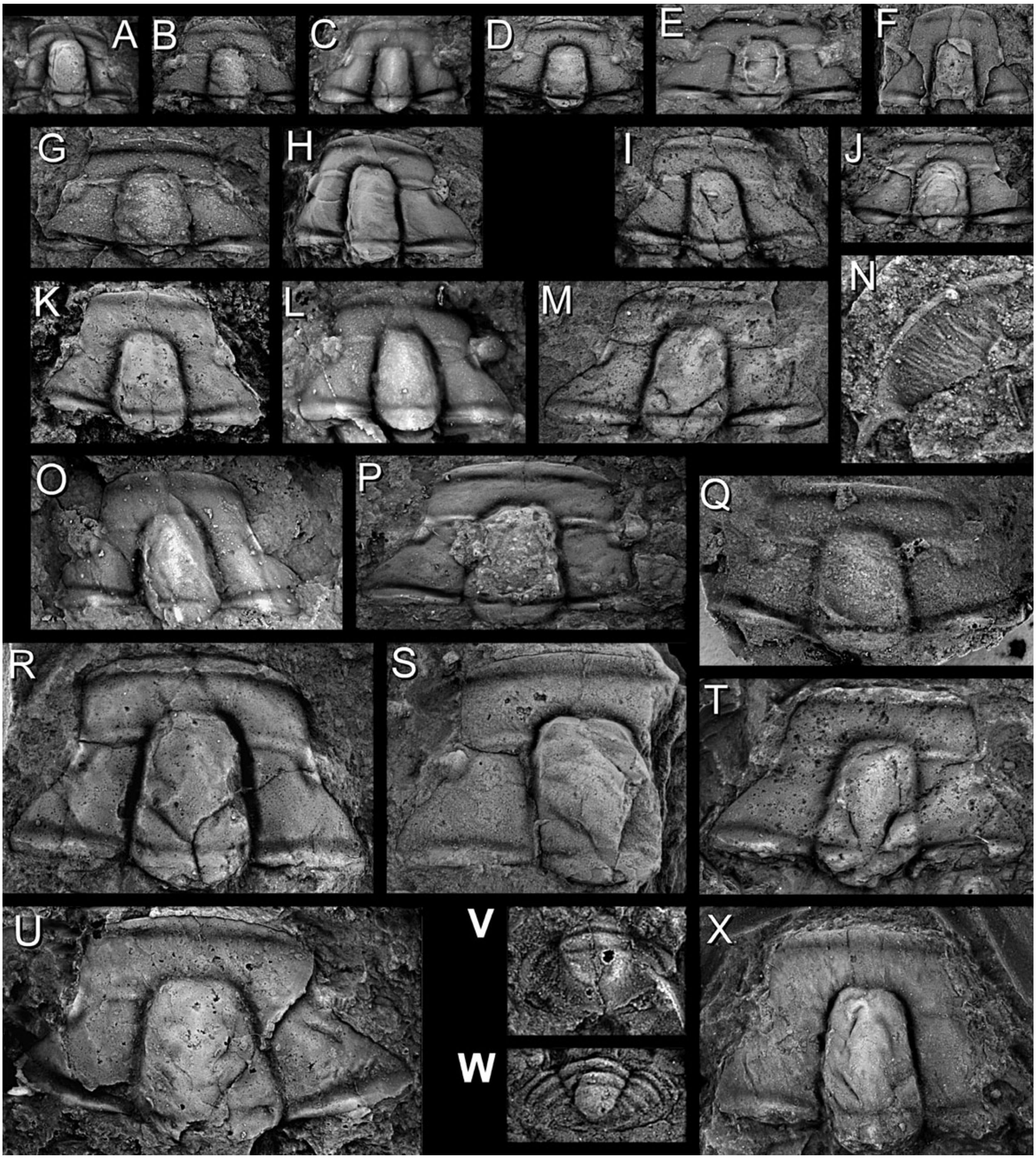


Figure 20. *Nangaops danzhaiensis* (Zhou *in* Lu *et al*., 1974a), all figures × 5 unless otherwise noted. • A – cranidium, exfoliated, GK B3 0159, FZX30. • B – cranidium, exfoliated, GK B3 0160, latex cast, FZX31. • C – cranidium, not exfoliated, GK B3 0161, latex cast, FZX31. • D – cranidium, exfoliated, GK B3 0162, FZX31. • E – cranidium, partially exfoliated, GK B3 0163, latex cast, FZX44. • F – cranidium, partially exfoliated, GK B3 0164, FZX43. • G – cranidium, calcite coated, GK B3 0165, FZX41. • H – deformed cranidium, exfoliated, GK B3 0166, FZX30. • I – cranidium, exfoliated, GK B3 0167, FZX40. • J – cranidium, partially exfoliated, GK B3 0168, FZX45. • K – cranidium, exfoliated, GK B3 0169, FZX45. • L – cranidium, not exfoliated, GK B3 0170, latex cast, FZX31. • M – cranidium, exfoliated, GK B3 0171, latex cast, FZX35. • N – librigena, exfoliated, GK B3 0172, FZX45, × 7.5. • O – cranidium, not exfoliated, GK B3 0173, latex cast, FZX41. • P – damaged cranidium, not exfoliated, GK B3 0174, latex cast, FZX44. • Q – cranidium, not exfoliated, granular surface possibly due to calcite coating, GK B3 0175, latex cast, FZX46. • R – cranidium, exfoliated, GK B3 0176, FZX32. • S – cranidium, exfoliated, GK B3 0177, FZX31. • T – cranidium, exfoliated, GK B3 0178, FZX46. • U – cranidium, exfoliated, GK B3 0179, FZX31. • V – damaged pygidium, exfoliated, GK B3 0180, FZX31, × 10. • W – pygidium, exfoliated, GK B3 0181, FZX35, × 10. • X – cranidium, exfoliated, GK B3 0182, FZX45.

1965 *Probowmania* (*Mufushania*) *changi* Lin, pp. 555, 559, pl. 1, fig. 12–17.
1983 *Mufushania changi* Lin, 1965. – Qiu *et al*., p. 68, pl. 22, figs 9.
1983 *Mufushania nankingensis* Lin, 1965. – Qiu *et al.*, p. 68, pl. 22, fig. 10.
1988 *Mufushania changi* Lin, 1965. – Zhu *et al*., p. 38, pl. 1, figs 3, 4.
1988 *Mufushania nankingensis* Lin, 1965. – Zhu *et al*., p. 38, pl. 1, fig. 6.
1989 *Mufushania nankingensis* Lin, 1965. – Xie, pl. 1, fig. 1, pl. 3, fig. 2.
1997 *Probowmania* (*Probowmania*) *balangensis* Yuan & Zhao (*in* Yuan *et al*.), pp. 509, 510, pl. 6, fig. 2.
1997 *Probowmania* (*Gunnia*) sp. Yuan & Zhao (*in* Yuan *et al*.), p. 510, pl. 6, fig. 3.
1999 *Xingrenaspis* (?) *quadratus* Yuan & Zhao (*in* Zhang *et al*., 1980). – Yuan *et al.*, p. 2, fig. 18–21.
2001 *Mufushania nankingensis* Lin, 1965. – Peng *et al.*, p. 238, pl. 1, figs 1–7, pl. 2, figs 1–3, 5–10.
2002 *Probowmania (Probowmania) balangensis* Yuan & Zhao (*in* Yuan *et al.*, 1997). – Yuan *et al.*, p. 155, pl. 44, figs 1–6, 11.
2002 *Probowmania (Mufushania) nankingensis* Lin, 1965. – Yuan *et al.*, p. 157, pl. 44, figs 7–10.
2002 *Probowmania* (*Gunnia*?) *himalaica* (Reed). – Yuan *et al.*, pp. 158, 159, pl. 44, fig. 12, 13, pl. 45, figs 2, 3.
2002 ?*Probowmania* (*Gunnia*?) *quadrata* (Yuan & Zhou *in* Zhang *et al.*, 1980). – Yuan *et al.*, p. 159, pl. 47, fig. 10–13, pl. 57, fig. 7.

Material. – 19 cranidia, 33 partial or complete shields.

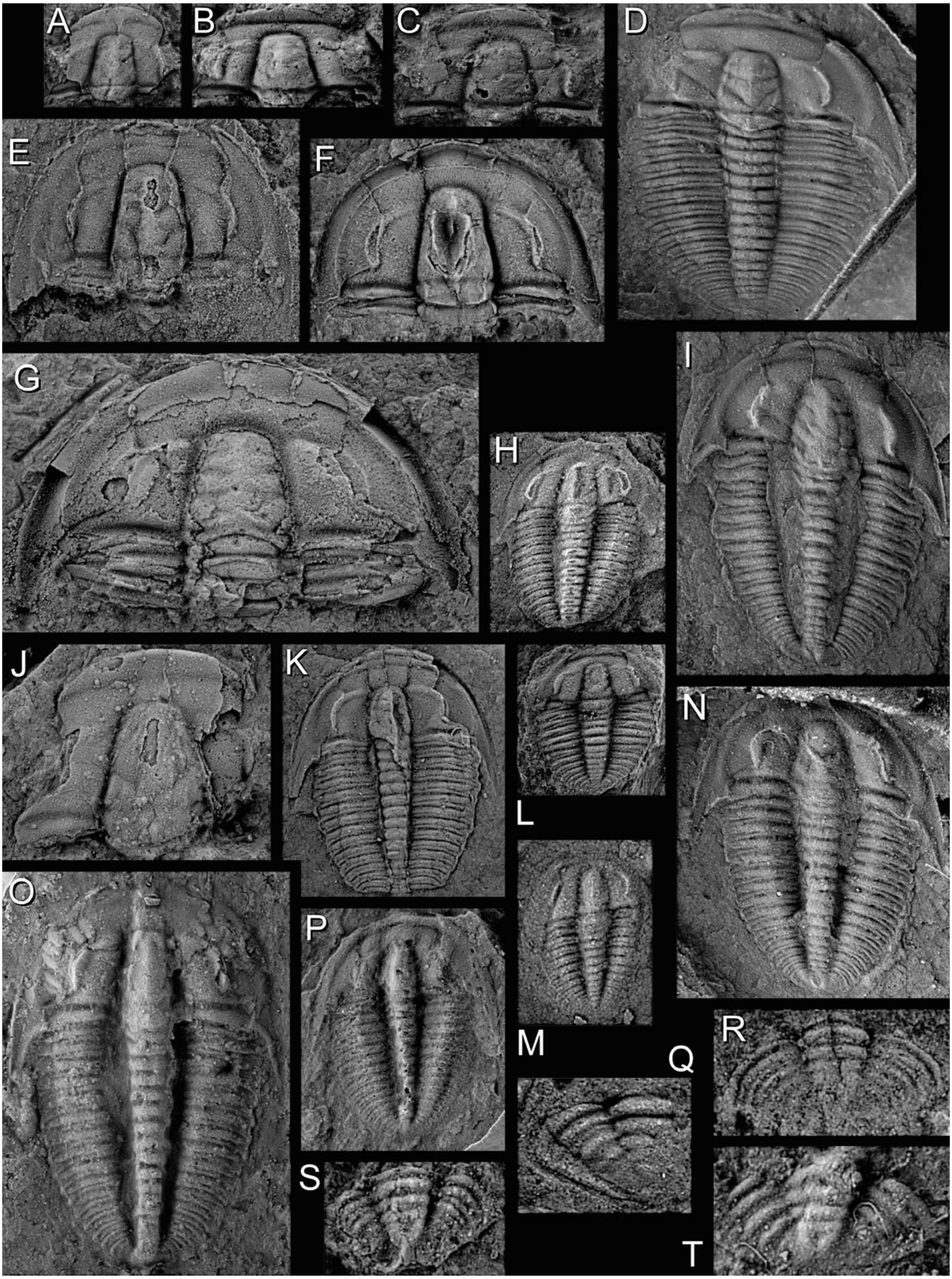
Emended diagnosis. – *Probowmania* with palpebral lobes twice as long as the posterior area of the fixigena (200%); ocular ridges directed slightly posterior-laterally and strong; glabellar length approximately 66% of cranidial length; preglabellar field length longer than anterior border (150%); anterior border convex, level, slightly tapering at lateral margins; facial sutures divergent anterior of palpebral lobes, very strongly divergent (approx. 90°) from the posterior end of palpebral lobes. Pygidium transversely elongated with anterior lateral corners located about the mid-length of the pygidium; doublure narrow at posterior margin, slightly wider at anterior margin; pleural furrows prominent, interpleural furrows weaker; pygidial axis with 3 rings, width about 2/3 pleural field width; rounded terminal piece that nearly reaches the anterior border. Well-preserved specimens illustrate a fine granular texture on the dorsal surface of the exoskeleton (Fig. 21F, I).

Remarks. – This species has a relatively truncate glabella with long palpebral lobes and strong ocular ridges directed nearly straight outwards. It is most similar to *Parashuiyella* Yuan & Zhao *in* Yuan *et al*., 1997, but differs in having a narrower anterior border, more segments in the pygidium, wider preglabellar area and wider fixigena. This species is also similar to *Kaotaia* Lu 1962, but differs in its stronger ocular ridges, longer palpebral lobes, elongated, less rectangular pygidium, less pronounced doublure on the thoracic segments and pygidium, and less tapered shield. Specimens of *Kaotaia magna* (Lu, 1945) are similar, but the anterior border is less convex and possibly upturned. *Kaotaia* typically includes a medial swelling in the preglabellar field, but is not always apparent on some specimens. Some specimens of *Probowmania* also have these swellings (Fig. 21F, K, P), but it cannot be established if they are the result of tectonic distortion and/or compaction.

Illustrated specimens of *Probowmania* (*Probowmania*) *balangensis* Yuan & Zhao *in* Yuan *et al.*, 1997 (pl. 6, fig. 2, Yuan *et al.* 2002, pl. 44, figs 1–6, 11) fall within the morphological range of the specimens of species found in the quarry section and the specimens of *Probowmania* (*Mufushania*) *nankinensis* illustrated by Peng *et al*. (2001, pl. 1, figs 1–7, pl. 2, figs 1–3, 5–10) and Yuan *et al.* (2002, pl. 44, figs 1–10). These two species also occur in the same horizons in the Wuliu-Zengjiayan section (Yuan *et al.* 2002).

The type specimens of *Ptychoparia*? *himalaica* Reed, 1910, illustrated as *Shantungaspis himalaica* (Reed) in Jell & Hughes (1997, pl. 11, figs 1–4, fig. 4 is the lectotype), are similar to *Probowmania balangensis*, but differ in the more rectangular glabella. If this shape of the glabella is reliable in the tectonically distorted specimens, then *S. himalaica* is a different species. Peng *et al.* (2009) placed *S. himalaica* into *Douposiella* Lu & Chang *in* Lu *et al.*, 1974a. If the specimens preserved in limestone illustrated by Peng

Figure 21. *Probowmania nankingensis* Lin, 1965, all figures × 7 except figures Q–T which are × 15. • A – damaged cranidium, partially exfoliated, GK B3 0183, FZX46. • B – cranidium, exfoliated, GK B3 0184, FZX45. • C – cranidium, mostly exfoliated, GK B3 0185, FZX45. • D – partial shield, not exfoliated, GK B3 0186, latex cast, FZX44. • E – cranidium, covered with calcite layer, GK B3 0187, FZX35. • F – cranidium with librigenae and two thoracic segments, mostly exfoliated, GK B3 0188, FZX43. • G – damaged cranidium, not exfoliated, GK B3 0189, FZX42. • H – partial shield, exfoliated, GK B3 0190, FZX39. • I – shield, not exfoliated, GK B3 0191, latex cast, FZX46. • J – partial cranidium, partially exfoliated, GK B3 0193, FZX41. • K – partial shield, partially exfoliated, GK B3 0193, FZX42. • L – shield, calcite coated, GK B3 0194, FZX34. • M – partial shield, not exfoliated, GK B3 0195, latex cast, FZX35. • N – nearly complete shield, not exfoliated, GK B3 0196, latex cast, FZX41. • O – shield, not exfoliated, GK B3 0197, latex cast, FZX40. • P – shield, partially exfoliated, GK B3 0198, latex cast, FZX41. • Q – partial pygidium, exfoliated, GK B3 0199, FZX46. • R – crushed pygidium, exfoliated, GK B3 0200, FZX46. • S – pygidium, partially exfoliated, GK B3 0201, FZX37. • T – pygidium, not exfoliated, GK B3 0202, latex cast, FZX45.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et al. (2009, fig. 29) are conspecific, then *Douposiella himalaica* is a distinct genus from *Probowmania* in its glabellar outline, rounded termination of the posterior area of the fixigena, and narrow (tr.) genal area of the librigena. However, the specimens of *Probowmania himalaica* illustrated by Yuan *et al.* (2002, pl. 11, figs 12, 13, pl. 45, figs 2, 3) could be tectonically stretched representatives of *P. nankinensis* and are thus included into this species.

Probowmania (*Gunnia*?) *quadrata* Yuan & Zhou *in* Zhang *et al.*, 1980, illustrated by Yuan *et al.* (2002) is questionably assigned to *P. nankinensis*. It has a wider fixigena and more quadrate glabella, although these could be the result of tectonic distortion. *Probowmania quadrata* occurs stratigraphically above *P. nankinensis* in the upper portion of the *O. indicus* Zone (= *O. orientalis* Zone of Yuan *et al.* 2002). *Xingrenaspis quadratus* Yuan & Zhou *in* Zhang *et al.*, 1980 (pl. 109, figs 14–19) has upturned anterior borders, narrower palpebral lobes, and weaker ocular ridges and is not considered conspecific with *P. nankinensis*.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* Zone: Wuliu Quarry levels FZX31, 32, 35, 36, 40, 41, 43–46; Wuliu-Zengjiayan and Miaobanpo sections, China.

Genus *Xingrenaspis* Yuan & Zhou (*in* Zhang *et al.*, 1980)

Type species. – *Xingrenaspis xingrenensis* Yuan & Zhou (*in* Zhang *et al.*, 1980).

Remarks. – Peng *et al*. (2009, pp. 63–65) synonymized the type species with *X. hoboi* (Resser & Endo *in* Endo & Resser 1937). This reassignment of the type species to *X. hoboi* we consider an error, see discussion below.

Xingrenaspis xingrenensis Yuan & Zhou (*in* Zhang *et al.,* 1980)

Figure 22A–Y

1980 ?*Wuxunaspis subquadrata* Yuan (*in* Zhang *et al.*); p. 325, fig. 92, pl. 107, fig. 16.

1980 *Xingrenaspis xingrenensis* Yuan & Zhou (*in* Zhang *et al.*), pp. 330, 331, fig. 94, pl. 108, figs 19, 20, pl. 109, figs 1–12, pl. 110, figs 5, 6.

1980 *Xingrenaspis quadratus* Yuan & Zhou (*in* Zhang *et al.*), p. 331, pl. 109, figs 14–16.

1980 *Xingrenaspis rectangularis* Yuan & Zhou (*in* Zhang *et al.*), p. 331, pl. 109, figs 13.

1980 *Xingrenaspis jialaoensis* Yuan & Zhou (*in* Zhang *et al.*), p. 332, pl. 108, fig. 14.

1980 *Xingrenaspis elongatus* Yuan & Zhou (*in* Zhang *et al.*), pp. 332, 333, pl. 109, figs 17–19.

1983 ?*Xingrenaspis politus* Lu & Qian, p. 39, pl. 4, fig. 11.

1997 ?*Xingrenaspis dardapurensis* (Reed, 1934). – Jell & Hughes, pp. 66, 67 (see for further synonymy of this species), pl. 18, figs 4–11, pl. 26, figs 1–11, not pl. 19, figs 1, 2.

2002 *Xingrenaspis xingrenensis* Yuan & Zhou (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 186, 274, pl. 45, fig. 10, pl. 46, figs 5–7, pl. 47, fig. 6, pl. 48, figs 1–10, pl. 49, figs 2–7.

2002 ?*Xingrenaspis primus* Yuan & Zhao (*in* Yuan *et al.*), pp. 187, 274, pl. 47, fig. 7.

2002 ?*Xingrenaspis politus* Lu & Qian, 1983. – Yuan *et al.*, pp. 187, 274, pl. 45, fig. 12, pl. 47, figs 3–5, pl. 49, figs 8, 9.

2002 *Xingrenaspis rectangularis* Yuan & Zhou (*in* Zhang *et al.*, 1980). – Yuan *et al.*, pp. 188, 275, pl. 46, figs 1–4.

2002 ?*Xingrenaspis granulosa* Yuan & Zhao (*in* Yuan *et al.*), pp. 188, 275, pl. 57, fig. 10.

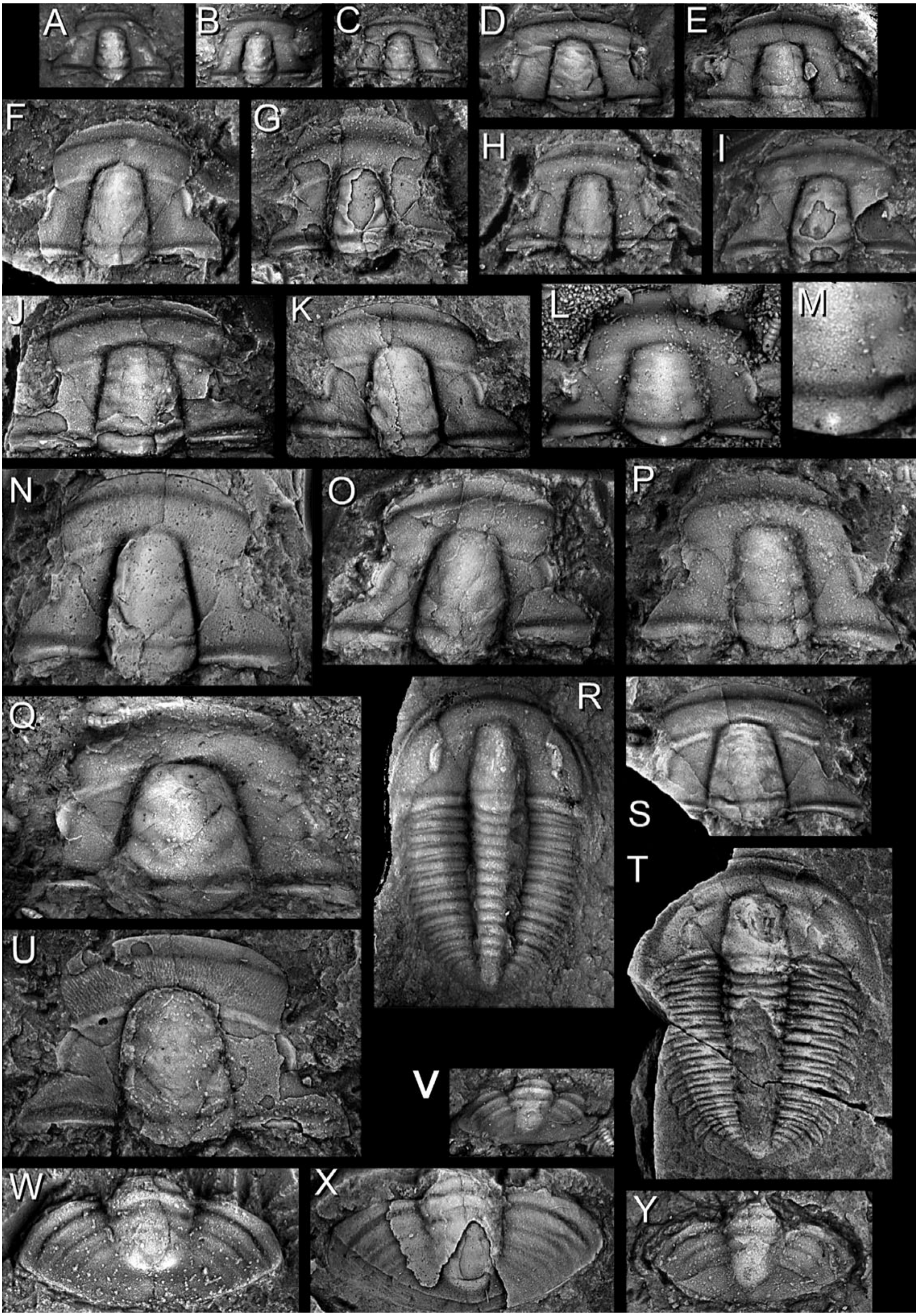
2009 *Xingrenaspis hoboi* (Resser & Endo *in* Endo & Resser, 1937). – Peng *et al.*, pp. 65, 66, fig. 42.1–42.5.

2010b *Douposiella guizhouensis* Yuan & Zhou (*in* Yuan *et al*., 2002). – Sundberg *et al*., fig. 1.

Material. – 489 cranidia, 54 pygidia, 11 partial or complete shields.

Emended diagnosis. – *Xingrenaspis* has palpebral lobes slightly shorter than the posterior area of the fixigena (85–95%); ocular ridges directed moderately posterior laterally; glabellar length approximately 70% of cranidial length; anterior border approximately 60–75% of preglabellar field, slightly convex (could be influenced

Figure 22. *Xingrenaspis xingrenensis* Yuan & Zhou *in* Zhang *et al*., 1980, all figures × 5 unless otherwise noted. • A – cranidium, exfoliated, GK B3 0203, FZX11, × 10. • B – cranidium, not exfoliated, GK B3 0204, latex cast, FZX10. • C – cranidium, exfoliated, GK B3 0205, FZX16. • D – cranidium, not exfoliated, GK B3 0206, FZX13. • E – cranidium, not exfoliated, GK B3 0207, latex cast, FZX13. • F – cranidium, partially exfoliated, GK B3 0208, FZX11. • G – cranidium, mostly exfoliated, GK B3 0209, FZX13. • H – cranidium, exfoliated, GK B3 0210, FZX16. • I – cranidium, partially exfoliated, GK B3 0211, FZX6. • J – cranidium, partially exfoliated, GK B3 0212, FZX13. • K – cranidium, exfoliated, GK B3 0213, FZX6. • L, M – cranidium, not exfoliated, GK B3 0214, latex cast, FZX2; M – closeup showing fine granules, × 10. • N – cranidium, exfoliated, GK B3 0215, FZX9. • O – cranidium, not exfoliated, GK B3 0216, FZX15. • P – cranidium, not exfoliated, GK B3 0217, FZX16. • Q – cranidium, not exfoliated, GK B3 0218, FZX16; latex cast. • R – shield, not exfoliated, GK B3 0219, latex cast, FZX6. • S – cranidium, not exfoliated, GK B3 0220, FZX2. • T – shield, exfoliated, internal mold, GK B3 0223, FZX3. • U – cranidium, not exfoliated, GK B3 0221, FZX9. • V – pygidium, not exfoliated, GK B3 0222, latex cast, FZX9. • W – pygidium, not exfoliated, GK B3 0224, FZX9. • X – pygidium, partially exfoliated, GK B3 0225, FZX9. • Y – pygidium, not exfoliated, GK B3 0226, FZX15.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by compaction), level to upturned, slightly tapering laterally; facial sutures moderately divergent anterior of palpebral lobes, strongly divergent (approximately 45°) from the posterior end of the palpebral lobes. Pygidium transversely elongated with anterior lateral corners located about the mid-length of the pygidium and doublure narrow at posterior margin, but nearly $^1/_3$ to $^1/_2$ of the anterior margin.

Remarks. – Because of the distortion, the relative length/width ratio of the cranidium and glabella varies considerably, ranging in morphology between *X. rectangularis* Yuan & Zhou *in* Zhang *et al*., 1980, to *X. quadratus*, to *X. elongatus* Yuan & Zhou *in* Zhang *et al*., 1980. Included in this range of morphologies is *X. jialaoensis* Yuan & Zhou *in* Zhang *et al*., 1980. These species are probably synonymous with *X. xingrenensis*. The anterior border ranges from very slightly to moderately concave and can be level to upturned. These features could also be the result of tectonic distortion and lithologic compaction of the mudstones. The anterior border furrow is also variable. In several specimens it is well defined, although shallow. Other specimens with more upturned anterior borders have furrows that are very shallow.

Peng *et al.* (2009) synonymized *X. xingrenensis* with *X. hoboi*, however the two species differ. Based on the illustration of the type material in Zhang & Jell (1987, pl. 83, figs 4–6, 6 is lectotype), *X. hoboi* differs from the type material of *X. xingrenensis* and the material found in the Wuliu Quarry in having longer palpebral lobes that have anterior and posterior ends aligning exsagittally and a stronger curvature; ocular ridges that are stronger and directly nearly at 90° to the glabella; posterior facial sutures that are more divergent; and pleural lobes and pygidium with a narrower doublure and the anterior-lateral corners nearly parallel with the anterior margin of the pygidium. However, the specimens illustrated by Peng *et al.* (2009, fig. 42.1–42.5) as *X. hoboi* match the characteristics of the type and quarry material of *X. xingrenensis* and are reassigned here.

Xingrenaspis brevicus Yuan & Zhou *in* Zhang *et al.*, 1980, and *X. curvus* Yuan & Zhou *in* Zhang *et al.*, 1980 are very similar species and may represent a single taxon. These species are preserved in limestone and differ from the specimens of *X. xingrenensis* in having a more strongly curved anterior border and wider preglabellar area. In contrast, *X. primus* Yuan & Zhao *in* Yuan *et al.*, 2002, and *X. politus* Lu & Qian, 1983 are preserved in shale and their strongly curved anterior border and wider preglabellar areas may be the result of tectonics. These two species are questionably included here to *X. xingrenensis*.

Xingrenaspis dardapurensis (Reed, 1934) is questionably assigned to this species because the specimens from India are strongly tectonically deformed and lack pygidia. The cranidia of *Xingrenaspis dardapurensis* illustrated by Jell & Hughes (1997) are very similar to *X. xingrenensis* with the exception of the specimen illustrated in plate 19, figures 1 and 2 (Jell & Hughes 1997), which has a very conical shaped glabella. If *X. dardapurensis* is the same species as that from the Kaili Formation, then it would be the senior synonym.

Zhang & Jell (1987, pp. 72, 73) placed several species named by Yuan & Zhou (*in* Zhang *et al.*, 1980) into synonymy with *X. hoboi*. However, many of the specimens of Yuan & Zhou (in Zhang *et al*., 1980) are poorly preserved and/or internal moulds with limonite coatings preventing accurate taxonomic determination (based on personal observation by FAS of the type specimens). Of those species listed by Zhang & Jell (1987), *Eosoptychoparia intermedia* Yuan *in* Zhang *et al*., 1980, *E. guizhouensis* Yuan *in* Zhang *et al*., 1980, *E. conica*, *Onchocephalus*? *sanwanensis* Yuan *in* Zhang *et al*., 1980, *Pachyapsis* (*Danzhaina*) *lilia* Yuan *in* Zhang *et al*., 1980, *P.* (*D.*) sp. Yuan *in* Zhang *et al*., 1980, *Wuxunaspis deltoidea* Yuan *in* Zhang *et al*., 1980, *W.*? *deflecta* Yuan *in* Zhang *et al*., 1980, *W.*? *guizhouensis* Yuan *in* Zhang *et al*., 1980, *Ptychoparia*? *nitida* Yuan *in* Zhang *et al*., 1980, *Elrathiella kailiensis* Zhou *in* Zhang *et al*., 1980, and *Elrathiella*? *bella* Yuan *in* Zhang *et al*., 1980 are not included in the above synonymy for *Xingrenaspis xingrenensis*.

Zhang & Jell (1987) and Peng *et al.* (2009) placed *Eosoptychoparia conica* and *E. intermedia* into *X. hoboi*. If the specimens of *E. conica* and *E. intermedia* illustrated by Yuan *et al.* (2002, pl. 52, figs 1–9, pl. 53, fig. 7–9, pl. 54, fig. 10) are conspecific with the type material, differences in the pygidium shape and absence of a wide marginal border would indicate that these species do not belong in *Xingrenaspis*. This does not, however, state that *E. conica, E. intermedia*, and *E. guizhouensis* are different species. These and *E. lilia* (Yuan *in* Zhang *et al.*, 1980), *E. mesembrina* Yuan & Zhao *in* Yuan *et al.*, 2002, and *E. typica* (Yuan *in* Zhang *et al.*, 1980) may be conspecific.

Onchocephalus? *sanwanensis* (Zhang *et al*. 1980, pl. 102, figs 3, 20) differs from *X. xingrenensis* in have longer palpebral lobes, ocular ridges nearly 90 degrees to the glabellar axis and a relatively narrow posterior area of the fixigena. *Ptychoparia*? *nitida* (Zhang *et al*., 1980, pl. 107, fig. 17) differs from *X. xingrenensis* in its more hour-glass shaped glabella. *Wuxunaspis deltoidea* (Zhang *et al*., 1980, pl. 107, figs 10–12), *W.*? *deflecta* (Zhang *et al*., 1980, pl. 107, figs 13, 14), and *W.*? *guizhouensis* (Zhang *et al*., 1980, pl. 107, fig. 15) generally have longer palpebral lobes and a narrower, parallel sided posterior area of the fixigena. Other sclerites of these taxa are unknown. *Wuxunaspis subquadrata* Yuan *in* Zhang *et al*., 1980 is questionably assigned to *X. xingrenensis* based on its overall shape, but the material is poorly preserved and has deeper glabellar furrows. *Elrathiella kailiensis* (Zhang *et al.*, 1980, pl. 118, figs 7, 8) and *Elrathiella*? *bella* (Zhang *et* *al.*, 1980, pl. 118, figs 9–12) are also not included into *X. xingrenensis* due to their longer and wider palpebral lobes and narrower (exsag.) posterior area of the fixigena.

Xingrenaspis shyamalae and *X. parthiva*, both named by Peng *et al.* (2009), are two closely related species, but are not *Xingrenaspis* based on the pygidia having a short bluntly rounded axis with only two segments, stronger interpleural furrows [similar to Alokistocaridae as revised by Sundberg 1999 (= Ehmaniellidae Sundberg, 1994)], and narrow margins and matching narrow doublure.

Occurrence. – Kaili Formation, *Ovatoryctocara* cf. *granulata-Bathynotus holopygus* to *Oryctocephalus indicus* zones: Wuliu Quarry levels FZX32, 25–1; Wuliu-Zengjiayan and Miaobanpo sections, China. Parahio Formation, *Oryctocephalites salteri* Zone: Parahio River section, India.

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