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Systematic revision of the oryctocephalid trilobite *Protoryctocephalus arcticus* Geyer & Peel, 2011 from the lower Cambrian (Stage 4) of Balang, South China

Revisión sistemática del trilobite oryctocefálido Protoryctocephalus arcticus *Geyer & Peel, 2011 del Cámbrico inferior (Piso 4) de Balang, China meridional*

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ABSTRACT

The oryctocephalid trilobites from the traditional 'lower-middle Cambrian' represent key tools for international correlation. The trilobite zones in South China around the Cambrian Series 2-Miaolingian are made using oryctocephalids. One of the trilobite zones suggested is based on *Protoryctocephalus arcticus*. *Protoryctocephalus* from the Balang area in South China was described as *Protoryctocephalus wuxunensis*, also from the Cambrian Series 2 of South China. However, *Protoryctocephalus* from Balang shows different morphological features such as different glabellar shape, presence of a transglabellar S1 and more segments in the trunk. These features match with *Protoryctocephalus arcticus* from the Cambrian Series 2 of Greenland.

Keywords: Trilobites; Miaolingian; Biostratigraphy; Greenland; China.

RESUMEN

Los trilobites oryctocefálidos del tránsito 'Cámbrico inferior-medio' representan herramientas clave para la correlación internacional. Las zonas de trilobites en China meridional a través del tránsito Serie cámbrica 2-Miaolingiense se basan en este grupo fósil. La base de una de estas zonas de trilobites se sitúa con la aparición de *Protoryctocephalus arcticus*. El género *Protoryctocephalus,* procedente del área de Balang en China meridional, fue descrito originalmente como *Protoryctocephalus wuxunensis*, también de la serie cámbrica 2 de China meridional. Sin embargo, en Balang *Protoryctocephalus* muestra diferentes caracteres morfológicos, tales como la forma glabelar, la presencia de un surco transglabelar S1 y más segmentos en el tronco (tórax + pigidio). Estos caracteres cuadran mejor con *Protoryctocephalus arcticus* de la Serie cámbrica 2 of Groenlandia.

Palabras clave: Trilobites; Miaolingiense; Biostratigrafía; Groenlandia; China.

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Introduction

The Cambrian Series 2-Miaolingian boundary interval in the Balang area, Guizhou Province, South China has provided one of the most abundant and highly variable trilobite faunas worldwide. This fact has made Balang one of the most suitable places to erect new stages by the International Subcommission on Cambrian Stratigraphy (ISCS). *Oryctocephalus indicus* was chosen to define the base of the former Cambrian Series 3 and Stage 5. Currently, the Working Group led by professors Zhao and Peng is working on the systematic and biostratigaphic revision of the Cambrian Series 2, Stage 4. An updated revision of the trilobite zones was presented by Zhao *et al*. (2017). One of the trilobite zones erected by Zhao *et al.* (2017) from the middle-upper part of the 'Tsinghsutung' Formation was the *Protoryctocephlus arcticus* Zone. Previously, this zone was assigned to the *Protoryctocephalus wuxunensis* Zone (Yuan *et al.,* 2002; Yuan & Esteve, 2015). Trilobites from this zone are crucial for our understanding of the evolution of the oryctocephalids, and for international correlation, but some systematic and taphonomic studies focused on them should be addressed before (e.g. Zhao *et al.*, 2015; Esteve *et al.*, 2017, 2018). Oryctocephalid specimens from the Balang area were interpreted as *P. wuxunensis*, but this interpretation was based on the poor comparison between the Balang specimens and *P. wuxunensis*. Geyer & Peel (2011) described *Protoryctocephalus arcticus* from the lower Cambrian of Greenland and pointed out the great resemble with *P. wuxunensis*. Preliminary comparisons of those specimens from the middle-upper part of the 'Tsinghsutung' Formation with the *P. articus* from Greenland led to the conclusion that the specimens from Balang belong to *P. arcticus* (see Luo *et al*., 2014; Zhao *et al.*, 2017). However, we re-describe and figure below the type species *Protoryctocephalus wuxunensis* and describe *Protoryctocephalus arcticus* from the middle-upper part of the 'Tsinghsutung' Formation.

Systematic Palaeontology

Material. More than 5,000 complete specimens (fully articulated) have been collected from the 'Tsinghsutung' Formation. Strata in Balang are mainly composed of grey to dark grey thin-bedded limestone, intercalated with grey-yellowish shale and mudstone, grey thin-bedded argillaceous limestone and grey thin- to medium-bedded dolomite in the upper part. These features may belong to the Tsinghsutung Formation but further work is necessary before we can confirm this. Thus we use the informal term 'Tsinghsutung' Formation for this facies at Balang. Some authors argue that this formation could belong to the Wuxun Formation but this is very unlikely (see details in Yuan & Esteve, 2015).

Terminology. Trilobite descriptive terminology follows Whittington & Kelly (*in* Kaesler, 1997).

Repositories. All the specimens described and discussed herein are housed in the collections of the College of Resource and Environment Engineering, Guizhou University (Q). The type material *Protoryctocephalus wuxunensis* Zhou (in Lu *et al*., 1974) is housed in the collections of the Nanjing Institute of Geology and Palaoentology (NIGPAS).

Family ORYCTOCARIDAE Hupé, 1953.
Subfamily Oryctocephalinae Beecher, 1897
Genus *Protoryctocephalus* Zhou (in Lu *et al*., 1974)

Type species. *Protoryctocephalus wuxunensis* Zhou (in Lu *et al.,* 1974) from the late early Cambrian of the Guizhou Province, South-West China.

Discussion. Geyer & Peel (2011, p. 510) stated that Chow (in Lu *et al.* 1974) (Zhou in Lu *et al*., 1974) described *Protoryctocephalus* but the correct authorship is Lu & Zhang (in Lu *et al.,* 1974).

Protoryctocephalus wuxunensis Zhou (in Lu et al., 1974)
Fig. 1A-B

v. 1974 *Protoryctocephalus wuxunensis* Zhou in Lu et al., p. 93, pl. 3-4
v. 2002 *Protoryctocephalus wuxunensis* Yuan et al., p. 94, pl. 14-1, 14-2.

Occurrence Uppermost part of Wuxun Formation, Cambrian Series 3, Stage 5, Guizhou Province, South China.

Description. Exoskeleton long, elliptical in outline, with smooth carapace. Size small, type material in average length ca. 8 mm and width ca. 5.2 mm. Axial furrow moderately deep. Cephalon semi-circular, moderately long (ca. 40% of total length), 1.5 times longer than wide, posterior margin slightly straight. Anterior border extremally narrow (sag.) (ca. 2% of cephalic length), slightly convex, shallow with very narrow anterior border furrow. Glabella from sub-rectangular to slightly expanded medially (bell-shaped), narrow (ca. 20% of cephalic length and ca. 24% of cranidial width), long (ca. 98% of cephalic length,

including occipital ring), and slighly rounded anteriorly. Four pit-like glabellar furrows, S4 very shallow. Occipital ring short (ca. 10% of cephalic length), pit-like furrowed laterally and shallower medially. Fixigenae moderately narrow between palpebral lobes (ca. 12% of cephalic width); eye ridge very fine and short. Posterolateral projection very short (exsag.) and narrow (tr.), ca. 10% of cephalic length, ca. 5% of cranidial width. Palpebral lobe moderately long (ca. 35% of glabellar length), crescent-shaped in outline. Anterior branch of suture very short, almost parallel to axial axis from γ to β (ca. 5 degrees) and also parallel from β to α, posterior branches divergent to axial axis (ca. 120 degrees) from ε to lateral furrow and slightly divergent from border furrow to ω. Trunk with 13 segments, thorax with 9 segments, wide and deep pleural furrow, well-defined anterior and posterior pleural bands, pleural segments straight. Pygidium micropygous (ca. 44% of total length), semi-circular in outline, axis tapering backward, with 4 axial rings, moderately wide pleural field (ca. 40% pygidium width), pleural furrows

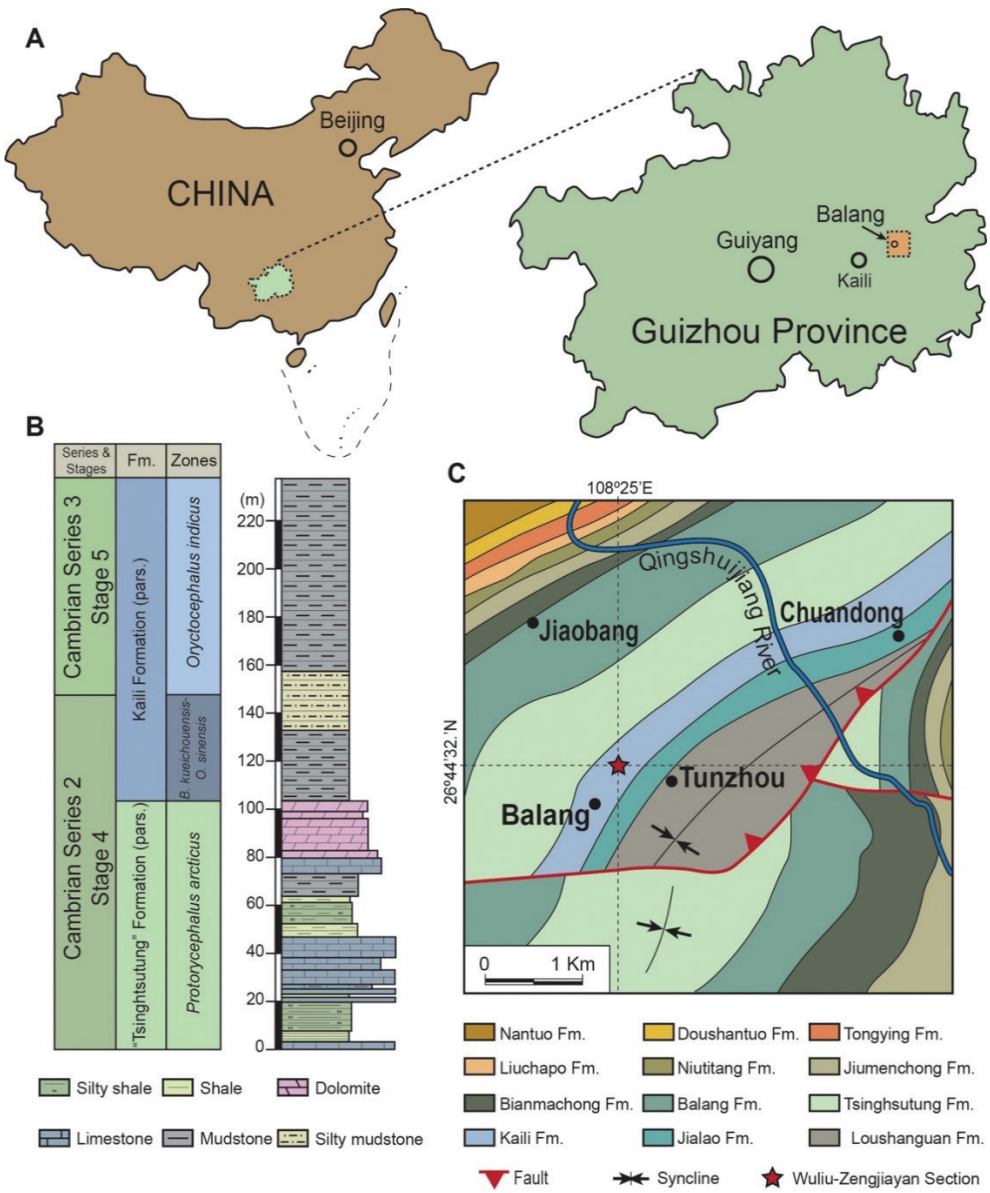

Figure 1.—Geological setting. A. Map of China showing the Guizhou Province and the Balang locality. B. Stratigraphic column of the upper part of the 'Tsinghsutung'Formation and the lower part of the Kaili Formation at the Wuliu-Zengjiayan Section showing the *Protoryctocephalus arcticus* Zone. C. Geological map of the Balang area; after Yuan & Esteve (2015).

well defined, deep, reaching pygidial edge, interpleural furrows shallow and shorter than pleural furrows.

Protoryctocephalus arcticus Geyer and Peel, 2011
Fig. 1C-H

v. 2015 *Protoryctocephalus wuxunensis* Yuan & Esteve, p. 360.

Occurrence. Middle and uppermost part of the 'Tsinghsutung' Formation, Cambrian Series 3, Stage 4, Balang, Guizhou Province, South China.

Description. Exoskeleton long, elliptical in outline, covered with barely visible tiny granular sculpture. Size small, in holapids average length ca. 8 mm and width ca. 5.2 mm. Axial furrow very shallow. Cephalon semi-circular, moderately long (ca. 40% of total length), 1.5 times longer than wide, posterior margin gently curved. Anterior border extremely narrow (sag.) (ca. 2% of cephalic length), slightly convex, shallow and very narrow anterior border furrow. Glabella inverted truncated, conical in shape, narrow (ca. 20% of cephalic length and ca. 24% of cranidial width), long (ca. 98% of cephalic length, including occipital ring), bluntly rounded anteriorly. Four pit-like glabellar furrows, S1 connected with shallow trans-glabellar furrows; in some specimens, S2 seems to be connected. Occipital ring short (ca. 15% of cephalic length), pit-like furrowed laterally and shallower medially. Fixigenae moderately narrow between palpebral lobes (ca. 12% of cephalic width); eye ridge well marked. Posterolateral projection very short (exsag.) and narrow (tr.) (ca. 10% of cephalic length, ca. 5% of cranidial width). Palpebral lobe moderately long (ca. 30% of glabellar length) and crescent-shaped in outline. Anterior branch of suture very short, almost parallel to axis from γ to β (ca. 5 degrees) and slightly more divergent from β to α; posterior branches divergent to axis (ca. 120 degrees) from ε to lateral furrow and almost parallel from border furrow to ω. Trunk with 15 segments, thorax with up to 12 segments in holaspids; pleural furrow wide and deep, with well-defined anterior and posterior pleural band; pleural segments straight. Pygidium micropygous (ca. 44% of total length), semi-circular in outline, axis tapering backward, with 7 axial rings, moderately wide pleural field (ca. 40% of pygidial width), pleural furrows well marked, deep, reaching pygidial edge, interpleural furrows shallow and shorter than pleural furrows.

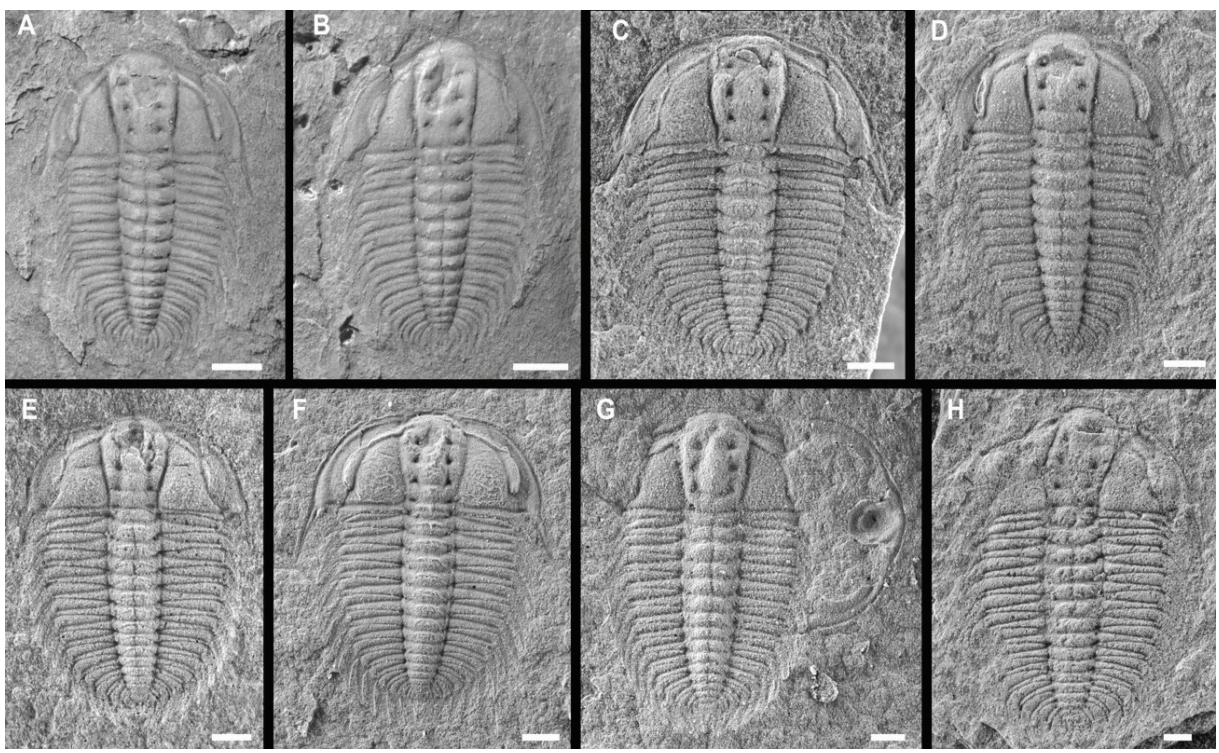

Figure 2.—A-B. *Protoryctocephalus wuxunensis* Lu & Zhang (in Lu *et al.*, 1974) from the uppermost part of the Wuxun Formation, Cambrian Series 3, Stage 5, Guizhou Province, South China. A. NIGPAS-21482a, Holotype. B. NIGPAS-21482b, Paratype. C-H. *Protoryctocephalus arcticus* Geyer & Peel, 2011, middle and uppermost part of the 'Tsinghsutung' Formation, Cambrian Series 3, Stage 4, Balang, Guizhou Province, South China. C. Q51-219; D. Q52-712B; E. Q52-1871; F. Q52-582; G. Q52-1212; H. Q52-1783. Scale bars = 1 mm.

Discussion and conclusions

Protoryctocephalus arcticus has been reported from the Cambrian Series 3, Stage 4 from Greenland by Geyer & Peel (2011) and from the "Tsinghsutung" Formation, Cambrian Series 3, Stage 5, Balang, Guizhou Province, South China by Zhao *et al.* (2017). However, the Chinese record was only cited but neither systematic description nor comparison was presented. *Protoryctocephalus wuxunensis* from the Wuxun Formation in the Guizhou Province, South China resembles *Protoryctocephalus arcticus* from Balang. Both species have large palpebral lobes situated in the middle part of the glabella, with a short anterior and posterior branch of the facial suture and shorter and narrower posterolateral projections. *P. arcticus* differs from *P. wuxunensis* in having an inverted truncated conical glabella, well-marked and longer eye ridges, shallow but well-developed transglabellar S1, and fifteen trunk segments. *P. arcticus* from Greenland has been reported only with isolated specimens. Morphological features of *P. arcticus* from Balang match with the population in Greenland, however most of the specimens from Greenland seem to have a smaller size and correspond to young holaspid or late meraspids. The morphological differences between these two populations will be addressed in a future work.

It seems reasonable to determinate the *Protoryctocephalus* species from Balang as a different species of those specimens found in the Wuxun Formation. The morphological features are pointing out that this *Protoryctocephalus* from Balang belong to the species *articus*. This fact makes *P. arcticus* an interesting trilobite for international correlation.

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