

Speciation of the genus *Arthricocephalus* Bergeron, 1899 (Trilobita) from the late Early Cambrian and its stratigraphic significance*

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Abstract The genus *Arthricocephalus* Bergeron, 1899 is revised, and *Halipanktos* Balkler & Peel, 1997 is suggested here as a senior synonym. The subgenus *Arthricocephalus* (*Arthricocephalites*) Chien & Lin in Lu et al., 1974 is considered as a separate genus. Of the 20 previously assigned species of *Arthricocephalus* (*Arthricocephalus*) Bergeron, 1899, *Arthricocephalus* (*Arthricocephalites*) Chien & Lin in Lu et al., 1974, *Arthricocephalus* (*Euarthricocephalus*) Ju, 1983 are lumped into eight species. The speciation trend of *Arthricocephalus* and *Arthricocephalites* is demonstrated based on their stratigraphic occurrences. It not only enhances the resolution of the biostratigraphic zonation in the uppermost Lower Cambrian, but also represents a potential candidate to define the Duyunian stage. The base of the stage is suggested at the first appearance datum (FAD) of *Arthricocephalus chauveaui* Bergeron, 1899 within the evolutionary lineage from *Ar. jiangkouensis* Yin in Yin & Li, 1978 to *Ar. chauveaui* in a global scale.

Keywords: late Early Cambrian, Duyunian stage, speciation of *Arthricocephalus* and *Arthricocephalites*, biostratigraphy.

Some oryctocephalid trilobites, including *Oryctocephalus indicus* (Reed, 1910), *Ovatoryctocara granulata* Tchernysheva, 1962, *Arthricocephalus chauveaui* Bergeron, 1899, *Tonkinella breviceps* Kobayashi, 1934, have worldwide occurrences and are strong candidates for making intercratonic correlation and recognizing global stage as well as series boundaries in the Cambrian^[1-8]. At the present time, some taxa lack precise stratigraphic information^[9,10]; while others were named based on the miniature size of juvenile specimens. Therefore, a more detailed research on oryctocephalid trilobites is needed. We suggest that the phylogeny of oryctocephalid trilobites is a very complicated evolutionary lineage for the following reasons^[3]: (1) the number of adult thoracic segments varies among oryctocephalid trilobites (e. g. *Oryctocephalina lancastrionides* Shergold, 1969 bears seventeen thoracic segments^[10]; *Thoracocara minuta* (Resser, 1939) bears only two thoracic segments^[11], and that is also true within the same genus (e. g., the oldest species of the genus *Arthricocephalus jiangkouensis* Yin in Yin and Li, 1978 bears eleven thoracic segments, and the youngest species *A. chauveaui* Bergeron, 1899 possesses only nine thoracic segments; the oldest species of the genus *Oryctocephalus* (*Eoryctocephalus*) *sinicus* Zhao and Yuan in Yuan et al., 2002 bears sixteen thoracic seg-

ments^[4], and the youngest species *O. (Oryctocephalus) burgessensis* Resser, 1938 possesses only seven thoracic segments^[12]); (2) the shape of the glabella is also variable, from truncated conical, parallel-sided, club-shaped, to drum-shaped; (3) the facial sutures can be proparian, gonatoparian, or opisthoparian; (4) the pygidium can vary from micropygous (e. g. *Lancastria* Kobayashi, 1935; *Protoryctocephalus* Zhou in Lu et al., 1974)^[13,21], macropygous (e. g. *Arthricocephalus* Bergeron, 1899; *Oryctocara* Walcott, 1908), to isopygous (e. g. *Arthricocephalites* Chien & Lin in Lu et al., 1974; *Ovatoryctocara* Tchernysheva, 1962; *Tonkinella* Mansuy, 1916; *Metabalangia* Qian & Yuan in Zhang et al., 1980; *Sandoveria* Shergold, 1969). (5) the current genus and species concepts of oryctocephalid trilobites are still controversial. For example, *Ovatoryctocara granulata* Tchernysheva, 1962 has been identified as *Oryctocara granulata* (Tchernysheva, 1962), or as a junior synonym of *Arthricocephalus chauveaui* Bergeron, 1899^[7,14-16].

Arthricocephalus Bergeron, 1899 is one of the most primitive oryctocephalid genera. It is not only widely distributed in South China, including southeastern Guizhou, western Hunan, northern Jiangxi, northwestern Zhejiang, eastern Jiangsu^[17-28], but also occurs in northern Greenland and Siberia^[7,29,30].

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Thus, species of *Arthricocephalus* plays an important role for correlating across different continents within the traditional late Early Cambrian and carries potential utilities for defining global Lower Cambrian Duyunian stage, or Lower/Middle Cambrian boundary.

McNamara et al.^[31] interpreted *Arthricocephalus chauveaui* Bergeron, 1899 as the oldest species of the genus. After reexamining the specimen of type species *A. chauveaui*, we suggest here that the type specimen of *A. chauveaui* should be a poorly preserved, meraspid specimen. Besides, the type section of the Balang Formation at Balang, 15 km from Duyun, eastern Guizhou, in which the type specimen of *A. chauveaui* was collected, is less than 100 m thick and bounded by faults, but the average thickness of Balang Formation is ranging from 382 to 641 m in southeastern Guizhou^[32]. Thus, the section near Duyun may only represent the upper portion of the Balang Formation. A revision of the genus *Arthricocephalus* is proposed below based on the new materials collected from other more complete sections of the Balang Formation.

1 Revision of the genus *Arthricocephalus* Bergeron, 1899

Type species: *Arthricocephalus chauveaui* Bergeron, 1899 from the Lower Cambrian Balang Formation of eastern Guizhou, China.

Synonyms: *Oryctocarella* Tomashpolskaya & Karpinski, 1961^[33], *Haliplanktos* Blaker & Peel, 1997^[7].

Emended diagnosis: Small rather flat oryctocephalid (holaspid individual about 7—12 mm in length) with proparian facial suture; glabella parallel-sided, with four pairs of chevron-shaped excavations isolating from axial furrows, of which S1—S3 normally connected across the sagittal line by shallow furrows, wider fixigenae between palperal lobes, palpebral lobe short, located anteriorly, 9—11 thoracic segments, macropygous pygidium with postero-medial indentation, axis narrow, with 3—4 axial rings, pleurae wide, pleural furrows deep, interpleural furrows distinct, pygidial border narrow, without distinct border furrow, and surface covered with granules or ridge-like granules.

Remarks: Genus *Arthricocephalus* (s.l.) previously consisted of three subgenera: *Arthricocephalus* (*Arthricocephalus*) Bergeron, 1899, *A.* (*Arthricocephalites*) Chien & Lin in Lu et al., 1974, and *A.*

(*Euarthricocephalus*) Ju, 1983. We regard them here as three separate genera. Whittington and others^[1,4,12] regarded *Euarthricocephalus* Ju, 1983 as a separate genus because of the presence of small lateral glabellar lobes, oval to elongated oval glabella with four pairs of rounded pits-like glabellar furrows and opisthoparian facial suture. *Arthricocephalus* (*Arthricocephalites*) Chien & Lin in Lu et al., 1974 was considered as synonymous with *Arthricocephalus* Bergeron, 1899^[7,31,34], but the latter one is interpreted here as a distinct genus based on its gonatoparian facial suture, anteriorly expanded glabella (even in the meraspid specimens), four pairs of deeply excavated lateral furrows, narrow fixigenae, 6—8 segmented thorax, larger pygidium without posteromedial indentation, 5—6 axial rings, pleural lobe with five to six pleural ribs, distinct pleural furrows, obscure interpleural furrows, narrow pygidial border, distinct border furrow, smooth surface or with very fine granules^[2]. Genus *Haliplanktos* Blaker & Peel, 1997^[7], in which the type species is *Arthricocephalus* (*Arthricocephalites*) *jishouensis* Zhou in Zhou et al., 1977, is a junior synonym of *Arthricocephalus* Bergeron, 1899. *A.* (*A.*) *jishouensis* Zhou in Zhou et al., 1977, is a conspecies with *A. chauveaui* Bergeron, 1899, thus, the specimens assigned to *H. jishouensis* (Zhou) from Greenland^[7] are here reassigned as *Arthricocephalites taijiangensis* (Yin in Yin & Li, 1978).

Occurrence: South China, Greenland and Siberia.

2 The revision of the species of the genera *Arthricocephalus* and *Arthricocephalites*

(1) *Arthricocephalus chauveaui* Bergeron, 1899 (Fig1. (d)—(e))

Lectotype: Cranidium EM90001b (Lane et al., 1988^[28]; Blaker & Peel, 1997^[7])

1899 *Arthricocephalus chauveaui* Bergeron^[17]

1960 *Oryctocara sibirica* Tomashpolskaya in Khalfin^[29]

1961 *Oryctocarella sibirica*, Tomashpolskaya & Karpinski^[33]

1961 *Arthricocephalus duyunensis* Chien^[18]

1977 *Arthricocephalus* (*Arthricocephalites*) *jishouensis* Zhou et al.^[22]

1980 *Arthricocephalus horridus* Qian & Lin in Zhang et al.^[24]

1983 *Arthrocoephalus fuyangensis* Ju^[26]

1997 *Arthrocoephalus chauveaui*, in Blaker & Peel^[7]

Diagnosis: Glabella slightly expanded forward, nine thorax segments, pygidium with gently posteromedial indentation, narrow axis with four axial rings, pygidial border very narrow; surface covered with fine granules and aligned granules.

Locality and horizon: Eastern and southeastern Guizhou, western Hunan; upper part of the Balang Formation; western Zhejiang, Dachenling Formation; Greenland, the Henson Gletscher Formation and Siberia, Lower Cambrian^[7, 29, 30].

(2) *Arthrocoephalus granulus* Qian & Lin in Zhou et al., 1977 (Fig. 1(b)—(c))

Holotype: Exoskeleton NIGP 38246 (Zhou et al., 1977^[22]; Zhang et al., 1980^[24])

1977 *Arthrocoephalus granulus* Qian & Lin in Zhou et al.^[22]

1980 *Arthrocoephalus* (*Arthrocoephalites*) *granulus*, in Zhang et al., 1980^[24]

1983 *Arthrocoephalus* (*Arthrocoephalites*) *granulus*, Ju^[26]

Diagnosis: Glabella almost parallel-sided, ten thorax segments, pygidium with broadly posteromedial indentation, short narrow axis with three axial rings, pygidial border very narrow; surface covered with random granules and aligned granules.

Remarks: This species has been considered as synonymous with *Arthrocoephalus chauveaui* Bergeron, 1899^[7, 28, 31]. It differs from *A. chauveaui* because of scylindrical glabella, ten thoracic segments and smaller pygidium with distinct broadly posteromedial indentation, shorter narrow axis with three axial rings; thus, we regard it as a separate species. The specimens from western Zhejiang assigned to *Arthrocoephalus* (*Arthrocoephalites*) *granulus*^[26] are here reassigned to *Ovatoryctocara* sp. due to the presence of four or five thoracic segments, larger pygidium with seven to eight axial rings.

Locality and horizon: Eastern Guizhou; lower-middle part of the Balang Formation.

(3) *Arthrocoephalus jiangkouensis* Yin in Yin & Li, 1978 (Fig. 1(a))

Holotype: Exoskeleton, Gt 174 (Yin & Li, 1978^[23])

Diagnosis: Glabella parallel-sided; narrow thorax consisting of eleven same-width segments, axial lobe tapers backward, pleurae with very short zigzag terminations; pygidium with strongly posteromedial indentation, narrow axis with four axial rings, deeper pleural and interpleural furrows on pleural area, pygidial border indistinct; surface covered with ridge-like granules and a few granules.

Remarks: *A. jiangkouensis* is the known oldest species of the genus. It is similar to *A. granulus* Chien and Lin in Zhou et al., 1977, but differs in bearing narrower glabella and axial lobe, 11 thoracic segments, longer and deeper pleural and interpleural furrows on pleural area, and stronger indentation of posteromedial indentation.

Locality and horizon: Eastern Guizhou; lower part of the Balang Formation.

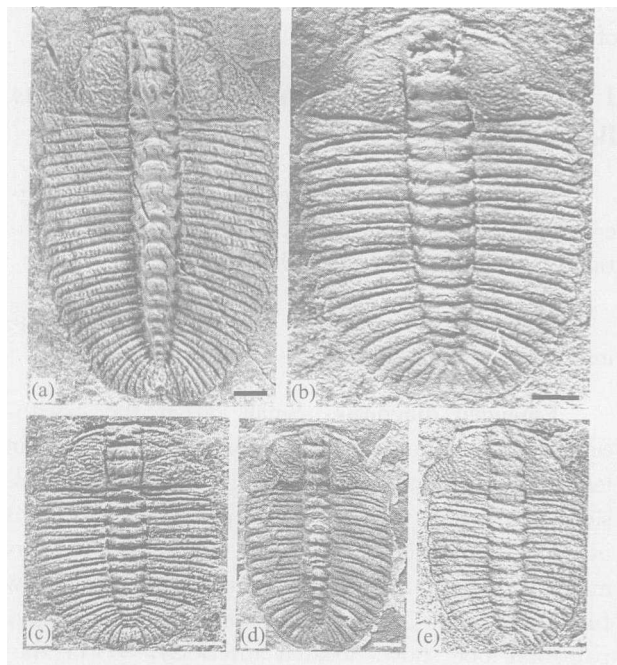


Fig. 1. (a) *Arthrocoephalus jiangkouensis*, GKT 1660, from the lower part of the Balang Formation, 614 m from the base of the Huanglian-Panmen section, near the Songtao County. (b)—(c) *Arthrocoephalus granulus*. (b) Holotype, NIGP 38246, from middle part of the Balang Formation, Xiunao-Feilongshan section (KH020), near the Songtao County, eastern Guizhou; (c) from the lower part of the Balang Formation, 624 m from the base of the Huanglian-Panmen section, near the Songtao County, GKT1661. (d)—(e) *Arthrocoephalus chauveaui*. (d) NIGP 38223, from the Balang Formation, Youmagou (2103), western Hunan; (e) NIGP 38232, from the Balang Formation, near the boundary between Hunan and Guizhou (0103TA). Scale bar = 1 mm.

(4) *Arthrocephalites xinzhaiheensis* Chien & Lin in Lu et al., 1974 (Fig. 2 (a) and (b))

Holotype: Exoskeleton, NIGP 38234 (Lu et al., 1974^[21]; Zhang et al., 1980^[24])

1974 *Arthrocephalus* (*Arthrocephalites*) *xinzhaiheensis* Chien & Lin in Lu et al.^[21]

2003 *Arthrocephalus xinzhaiheensis*, McNamara et al.^[31]

Diagnosis: Glabella expanded frontward from S3, with four pairs of pit-like lateral furrows isolating from axial furrows, of which S1 to S3 connected by transversal furrows in sagittal line; fixigenae narrow between palpebral lobes; eight thoracic segments; semicircular pygidium, with five axial rings and five pleural ribs, pleural furrows deep, interpleural furrows shallow; pygidial border narrow, border furrow distinct; surface smooth or with very fine granules.

Remarks: This is the type species of the genus *Arthrocephalites*, and it differs from *Arthrocephalus chauveaui* Bergeron, 1899 in having narrower fixigenae between palpebral lobes, more expanded glabella frontward from S3, eight thoracic segments, semicircular pygidium with distinct border furrow, five pairs of pleural ribs instead of four pairs of pleural segments in the latter, without posteomedial indentation and smooth surface.

Locality and horizon: Eastern Guizhou; upper part of the Balang Formation.

(5) *Arthrocephalites balangensis* Lu & Chien in Yin & Li, 1978

Holotype: Incomplete exoskeleton, NIGP 38240 (Yin & Li, 1978^[23]; Zhang et al., 1980^[24])

1978 *Arthrocephalus* (*Arthrocephalites*) *balangensis* Lu & Chien in Yin & Li^[23]

1978 *Arthrocephalus* (*Arthrocephalites*) *tongrenensis* Yin in Yin & Li^[23]

1980 *Arthrocephalus* (*Arthrocephalites*) *balangensis* Qian & Lin in Zhang et al.^[24]

2003 *Arthrocephalus balangensis* Qian & Lin, in McNamara et al.^[31]

Diagnosis: Glabella strongly expanded frontward from S3; seven thorax segments; semicircular pygidium, with six axial rings and five pairs of pleural ribs, pleural furrows deep, interpleural furrows obscure;

pygidial border narrow, border furrow distinct; surface smooth.

Locality and horizon: Eastern Guizhou; upper part of the Balang Formation.

(6) *Arthrocephalites taijiangensis* (Yin in Yin & Li, 1978) (Fig. 2 (c)—(j))

Holotype: Exoskeleton Gt 179 (Yin & Li^[23])

1978 *Arthrocephalus taijiangensis* Yin in Yin & Li^[23]

1980 *Arthrocephalus* (*Arthrocephalites*) *pulchellus* Zhang & Qian in Zhang et al.^[24]

1997 *Haliplanktos jishouensis* (Zhou in Zhou et al., 1977), Blaker & Peel^[7]

2002 *Arthrocephalites taijiangensis* (Yin), Yuan et al.^[4]

2003 *Arthrocephalus pulchellus* Zhang & Qian, McNamara et al.^[31]

Diagnosis: Glabella strongly expanded frontward from S3; six thoracic segments; semicircular pygidium, with six axial rings and six pairs of pleural ribs, pleural furrows deep, interpleural furrows obscure; pygidial border narrow, border furrow distinct; surface with very fine granules.

Remarks: The exoskeleton assigned to holotype of this species with five thoracic segments is 6.6 mm in length. It is evident that the holotype represents a meraspid specimen because that the adult individuals should bear six thoracic segments. We find no distinguishable differences between *Arthrocephalites taijiangensis* and *Arthrocephalus pulchellus* Zhang & Qian in Zhang et al., 1980. Thus, we consider *Arthrocephalus pulchellus* as synonymous with *Arthrocephalites taijiangensis*.

Locality and horizon: Eastern and southeastern Guizhou; from upper part of the Balang Formation to lower part of the Tsinghsutung Formation; Greenland, lower part of the Henson Gletscher Formation.

(7) *Arthrocephalites intermedius* Zhou in Lu et al., 1974

Holotype: Exoskeleton NIGP21481, Lu et al., 1974^[21]

1974 *Arthrocephalus* (*Arthrocephalites*) *intermedius* Zhou in Lu et al.^[21]

1985 *Arthrocephalus tenuis* Zhang & Zhou^[27]

Diagnosis: Glabella long, gently expanded forward from S3; fixigenae narrow between palpebral lobes; thorax of six segments; semicircular pygidium with short axis of five rings, pleural lobe broad, with five pairs of pleural ribs, pleural furrows deep, interpleural furrows obscure; pygidial border narrow, border furrow distinct; surface with coarse granules.

Locality and horizon: Southeastern Guizhou; the middle part of the Wuxun Formation; Kunshan, southern Jiangsu, upper part of Lower Cambrian.

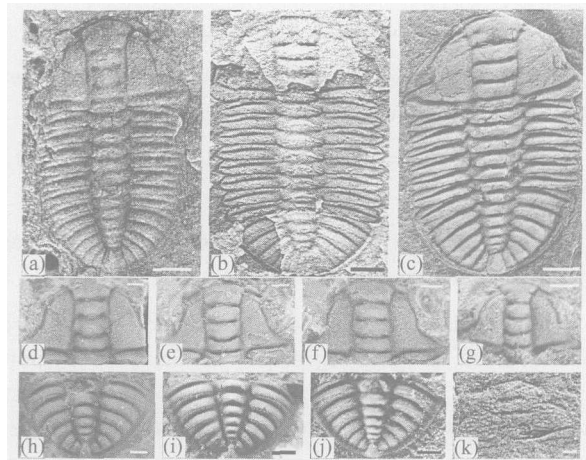


Fig. 2. (a)—(b) *Arthrocephalites xinzhaiheensis*. (a) Holotype, NIGP 38234, from uppermost part of the Balang Formation, Panxin; (b) GKT1661, from the upper part of the Balang Formation, 789 m from the base of the Huanglian-Panmen section, near the Songtao County. (c)—(j) *Arthrocephalites taijiangensis*. (c) NIGP 38233, from the Balang Formation, near the boundary between Hunan and Guizhou provinces (0103TA); (d) GK1232; (e) GK 1234; (f) GK6004; (g) GK1230; (h) GK1233; (i) GK6005; (j) GK 1231. (c)—(j) From lower part of the Tsinghsutung Formation of the Wuhe section, near Gedong Town. (k) *Arthrocephalites* sp. GKT 1662, from the lowermost part of the Kaili Formation of the Wuli-Zengjiayan section (BB1-13-43a), Black scale bar = 1 mm, white scale bar = 0.5 mm.

(8) *Arthrocephalites* (?) *xiaosaiensis* Qian in Zhang et al., 1980

Holotype: Cranidium NIGP38244 (Zhang et al., 1980^[24])

1980 *Arthrocephalus* (*Arthrocephalites*) Qian in Zhang et al.^[24]

Diagnosis: Glabella long, gently expanded forward from S3, S1—S3 rounded pits not connected in saggital line; fixigenae narrow between palpebral lobes; ten thoracic segments; smaller elliptical pygidium with short axis of five rings, pleural lobe broad,

with four pairs of pleural ribs, pleural furrows deep, interpleural furrows obscure; pygidial border narrow, border furrow distinct; surface smooth.

Remarks: This species is assigned to *Arthrocephalites* with question mark because of the different pattern of glabellar furrows, rather smaller pygidium. It co-occurs with *Arthrocephalus* (*Arthrocephalites*) *pectines* Qian in Zhang et al., 1980^[24], which should be now *Cheiruroides* Kobayashi, 1935 because of the parallel-sided glabellar outline and the linear grooves glabellar furrows^[24].

Locality and horizon: Eastern Guizhou; the uppermost part of the Jindingshan Formation.

(9) *Arthrocephalites* sp. (Fig.2 (k))

Diagnosis: Glabella broad and short, strongly expanded forward from S3; fixigenae narrow between palpebral lobes; thorax and pygidium unknown; surface with coarse granules.

Locality and horizon: Eastern Guizhou; the lowermost part of the Kaili Formation.

3 The phylogeny of the species of the genera *Arthrocephalus* and *Arthrocephalites* and its biostratigraphical significance

The evolutionary lineage of *Arthrocephalus* is the *A. jiangkouensis*-*A. granulus*-*A. chauveaui* series. Putative synapomorphies include proparian facial suture; parallel-sided glabella, wider fixigenae between palpebral lobes, palpebral lobe short, located anteriorly, macropygous pygidium with posteromedial indentation, border narrow without distinct border furrow, and surface covered with ridge-like granules. Pedomorphic trends show a reduction in number of thoracic segments, reduction in width of the thoracic pleurae, reduction in curvature of posteromedial indentation on pygidium, reduction in width of the cephalon and development of more transverse, and less pit-like glabellar furrows.

The evolutionary lineage of *Arthrocephalites* is the *A. xinzhaiheensis*-*A. balangensis*-*A. taijiangensis*-*A. intermedius* series. Putative synapomorphies include gonatoparian facial suture; strongly expanded glabella from S3 (even in the meraspid specimens); narrow fixigenae; isopygous pygidium without posteromedial indentation; axis with five to six rings; pleural lobe with five to six pleural ribs, nar-

row pygidial border, distinct border furrow; smooth surface or with very fine granules. Pedomorphic trends show a reduction in number of thoracic segments, increase in number of pygidial axial rings and pleural ribs, reduction in width of the fixigenae be-

tween palpebral lobes, reduction in width of the cephalon and development of more transverse, less pit-like glabellar furrows. These morphological changes can be explained by progenesis^[31,35,36] and shown in Fig. 3.

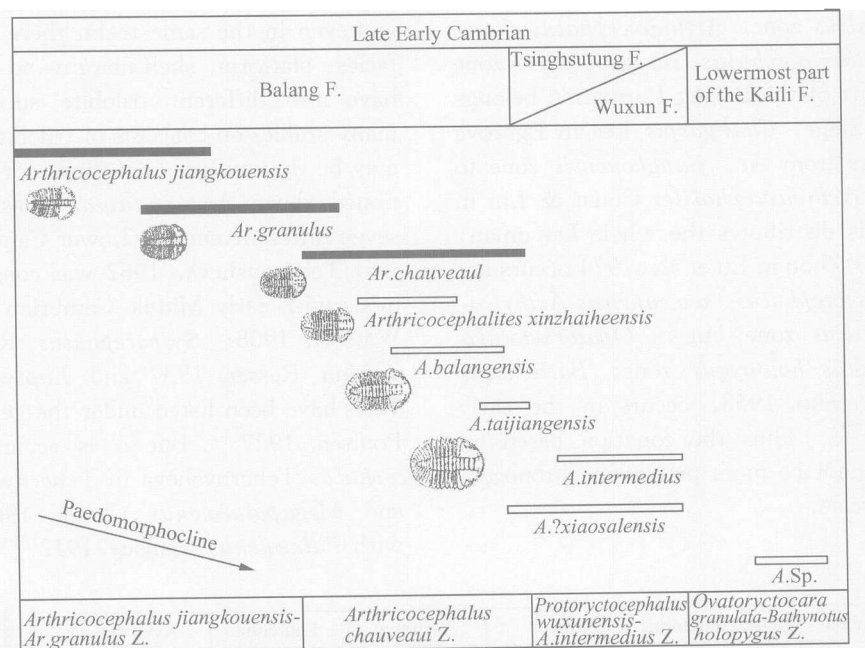


Fig. 3. Heterochronic evolution of species of *Arthricocephalus* Bergeron, 1899 and *Arthricocephalites* Chien & Lin in Lu et al., 1974, showing the development of a pedomorphocline between eight species and the zonation of late Early Cambrian in southeastern Guizhou, South China (Modified after McNamara et al., 2003).

Zonation and correlation of the uppermost Lower Cambrian (The Balang Formation, Wuxun Formation and lowest Kaili Formation) in eastern and southeastern Guizhou has been erected^[32,2]. According to the present study, we propose the following zonation in a descending order: (4) *Ovatoryctocara granulata*-*Bathynotus holopygus* Biozone is the uppermost biozone of the late Early Cambrian. The base of this biozone is marked by the first appearance datum (FAD) of *Ovatoryctocara granulata*, and the upper limit is defined based on the FAD of *Oryctocephalus indicus*. (3) *Protoryctocephalus wuxunensis*-*Arthricocephalites intermedius* Biozone. The lower limit of this biozone is recognized by the FAD of *Arthricocephalites intermedius*, and the upper limit is defined by the FAD of *Ovatoryctocara granulata*. (2) *Arthricocephalus chauveauli* Biozone. The lower limit of this biozone is marked by the FAD of *Arthricocephalus chauveauli*, and the upper limit is defined based on the FAD of *Arthricocephalites intermedius*. (1) *Arthricocephalus jiangkouensis*-*Ar. granulus* Biozone. The lower limit of this biozone is

defined based on the FAD of *Arthricocephalus jiangkouensis*, the upper limit is marked by the FAD of *Arthricocephalus chauveauli*.

4 Correlation between the Duyunian Stage and global synchronous strata in Siberia, Australia, Laurentia and Avalonian

The Duyunian Stage was originally established by Peng^[37] and revised by Peng and Babcock^[38]. The base of the stage is marked by the first appearance datum (FAD) of *Arthricocephalus chauveauli*, the upper limit is defined by the FAD of *Oryctocephalus indicus*; the stage consists of four trilobite zones in a descending order of *Bathynotus* zone, *Protoryctocephalus* zone, *Arthricocephalites-Changaspis* zone, and *Arthricocephalus* zone. After restudy on speciation of the genera *Arthricocephalus* Bergeron, 1899 and *Arthricocephalites* Chien & Lin in Lu et al., 1974, the Duyunian Stage needs to be reevaluated. Therefore the new definition of the stage is as follows: The base of the stage is marked by the FAD of *Arthricocephalus chauveauli* within the evolutionary

lineage from *Ar. jiangkouensis* Yin in Yin & Li, 1978 to *Arthrocephalus chauveaui*; the upper limit is defined by the FAD of *Oryctocephalus indicus*; the stage consists of three trilobite zones in a descending order: *Ovatoryctocara granulata-Bathynotus holopygus* zone, *Protoryctocephalus wuxunensis-Arthrocephalites intermedius* zone, *Arthrocephalus chauveaui* zone. *Arthrocephalus jiangkouensis* zone from the lower part of the Balang Formation belongs to the Nangaoan Stage. *Changaspis* Lee in Egorova et al., 1963 occurs from *Ar. jiangkouensis* zone to upper Duyunian; *Arthrocephalites* Chien & Lin in Lu et al., 1974 is distributed the whole Duyunian; *Protoryctocephalus* Zhou in Lu et al., 1974 occurs not only in *Protoryctocephalus wuxunensis-Arthrocephalites intermedius* zone, but in *Ovatoryctocara granulata-Bathynotus holopygus* zone; *Bathynotus anabarensis* Lazarrenko, 1958, occurs in the early Middle Cambrian^[39]. Thus the zonation based on trilobite genera cannot be more precise in chronocorrelation in global scale.

At present a quest for a globally recognizable stage subdivision and correlation of the traditional Lower Cambrian is very difficult^[40], because it is subjected to three different faunal realms: oriental realm (redlichiid fauna), occidental realm (olenellid fauna) and intermediate realm (paradoxidid fauna), and even in the same realm there are three different facies; platform, shelf margin and slope facies, which have also different trilobite successions. Besides, many studies on concepts of trilobite genera or species may be thrown into confusion, for instance, as mentioned above *Ar. chauveaui* has been recorded in seven different names; Lower Cambrian *Ovatoryctocara* Tchernysheva, 1962 was considered as synonymous with early Middle Cambrian genus *Oryctocara* Walcott, 1908; *Syspacephalus* Resser, 1936, *Elrathina* Resser, 1937 and *Eoptychoparia* Rasetti, 1955 have been listed under the genus *Ptychoparella* Poulsen, 1927^[7]. But it is accurate that *Schistocephalus* Tchernysheva in Tchernysheva et al., 1956 and *Megapalaeolenus* Chang, 1966 were grouped with *Palaeolenus* Mansuy, 1912^[41].

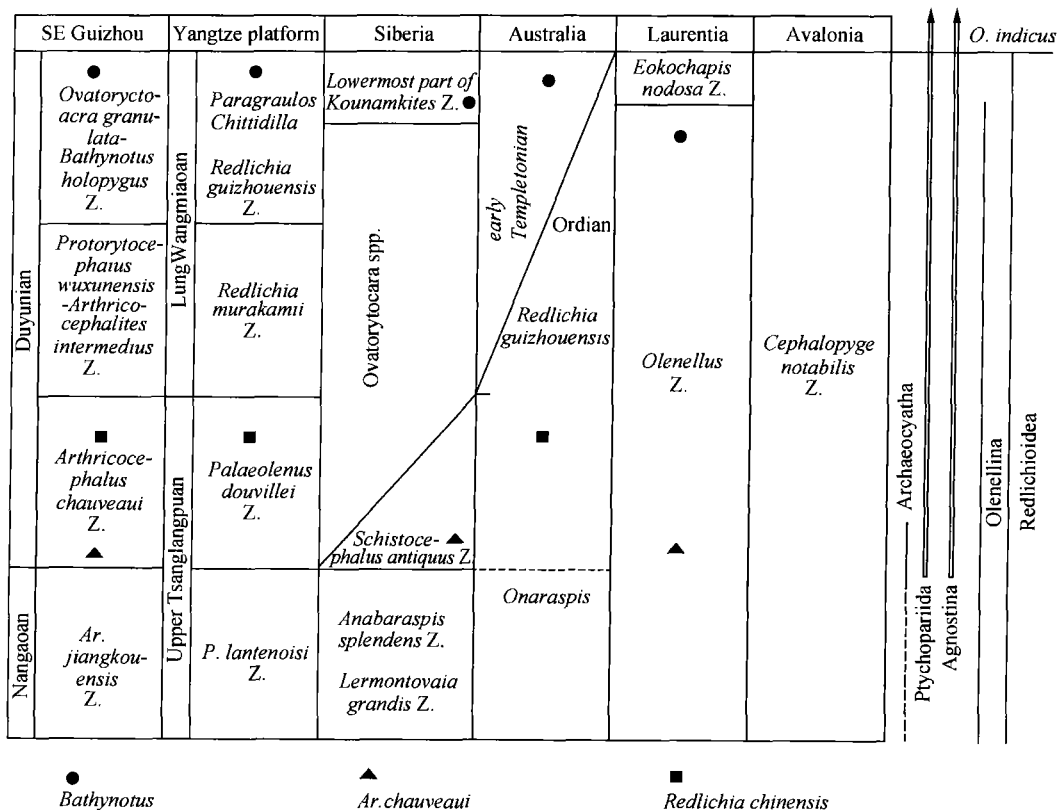


Fig. 4. A correlation chart between the Duyunian Stage and its synchronous strata in Siberia, Australia, Laurentia and Avalonian.

Although several authors have dealt with the problem of a correlation of the late Early Cambri-

an^[42-45]. In general, many problems have not been solved. For example, Lower Cambrian *Redlichia no-*

bilis zone has been correlated with early Middle Cambrian *T. gibbus* Zone; *Redlichia chinensis* zone is corresponding to early Middle Cambrian *Kounamkites* zone in Siberia^[43], meanwhile *Amecephalus arrososensis* zone of lower Delamaran Stage has been correlated with upper Duyunian Stage^[40].

Duyunian Stage was established in slope facies of SE Guizhou, South China and is correlated with upper part of the Canglangpuan Stage as well as with Longwangmiaoan Stage involving the Longwangmiao Formation and lowmost part of the Douposi Formation which yields trilobites *Paragraulos*, *Chittidilla*, *Probowmania* (*Mufushania*), *Bathynotus* etc. (see Fig. 4).

In Siberia Cambrian can also be divided into three facies: platform (Turnkhan-Irkutsk-Olekma facies), shelf margin (Anabar-Syn facies) and slope (Judoma-Olenek facies)^[46]. The lower part of the Duyunian may correlate with the base of *Schistocephalus antiquus* zone or the base of *Ovatoryctocara* zone because of the coexistence of *Ar. chauveaui*; the upper part of the Duyunian Stage may be corresponding to the lowest part of the *Kounamkites* zone due to the occurrence of the *Bathynotus*.

In Laurentia *Oryctocephalus americanus* Sundberg & McCollum, 2003 from the *Amecephalus arrososensis* zone of the lower part of the Delamaran Stage is here considered as synonymous with *O. indicus* (Reed, 1910), therefore *Amecephalus arrososensis* zone is correlated with *O. indicus* zone of the Taijiangian Stage. The *Eokochaspis nodosa* zone of the lowest Delamaran Stage may be corresponding to upper part of the Duyunian Stage, because morphologically *Eokochaspis nodosa* is quite similar to *Probowmania* (*Mufushania*) *nankingensis* Lin, 1965 from the upper part of the Duyunian Stage. The upper part of the *Olenellus* zone may correlate with the lower and middle parts of the Duyunian Stage, because *Bathynotus holopygus*, *Ar. chauveaui*, *Goldfieldia*, *Bonnia*, *Olenoides* co-occur in both regions.

In Australia the overlap of the Ordian and the early Templetonian stages has been pointed out^[47]; the concept of the lower limit of the stages is unclear. Nevertheless, the stages contain a rich trilobite fauna including *Redlichia chinensis*, *R. guizhouensis*, *Xystridura*, *Dinesus*, *Gunnia*, *Kootenia*, *Lyriaspis*, oryctocephalids. Because of the occurrence of *Redlichia chinensis*, the lower limit of the stages

should be correlated with lower Duyunian Stage. Traditionally, *Xystridura* fauna was regarded as early Middle Cambrian in age; it is widely distributed in Australia, Antarctica, Hainan, South China and northern Tianshan, northern Gansu, Northwest China. However, in Australia the *Xystridura* fauna consists of *Barklyella expansa* Shergold, 1969, which occurs in NE Guizhou associated with *Ovatoryctocara granulata*^[4]. In Antarctica the *Xystridura* fauna contains *Goldfieldia ninguis* Palmer & Gatehouse, 1969, but *Goldfieldia* is an index-fossil of the Lower Cambrian *Olenellus* zone in Laurentia. In northern Tianshan the *Xystridura* fauna comprises *Yukonides tianshanensis* Xiang & Zhang, 1985, but *Yukonides Fritz*, 1972 represents an index-fossil of Lower Cambrian in Laurentia. Recently *Pagetia luoyacunensis* Lin & Jago, 1993 from the *Xystridura* fauna in Hainan was transferred to *Kiskinella* Romanenko & Romanenko, 1962^[40] which occurs in Siberia and SE Newfoundland associated with *Ovatoryctocara granulata*. Therefore the *Xystridura* fauna perhaps falls into the Duyunian Stage, but may rang into traditional early Middle Cambrian Taijiang Stage.

In Avalonia, Acadian Stage consists of three trilobite zones in a descending order: *Eccaparadoxides etemincus* zone, *Acadoparadoxides harlani* zone, and *Cephalopyge notabilis* zone. *Cephalopyge notabilis* zone is correlated with the Duyunian Stage because of occurrence of *Kiskinella cristata*, *Ovatoryctocara granulata*, *Acidiscus theristes* in it^[40].

5 Conclusion

After study on the speciation of *Arthricocephalus* and *Arthricocephalites* the subgenus *Arthricocephalus* (*Arthricocephalites*) Chien & Lin in Lu et al., 1974 is considered as a separate genus, two genera may have a common ancestor, but no directly evolutionary affinity. A new definition of the Duyunian Stage is as follows: The base of the stage is marked by the FAD of *Arthricocephalus chauveaui* within the evolutionary lineage from *Ar. jiangkouensis* Yin in Yin & Li, 1978 to *Arthricocephalus chauveaui*; the upper limit is defined by the FAD of *Oryctocephalus indicus*; the stage consists of three trilobite zones in a descending order: *Ovatoryctocara granulata*-*Bathynotus holopygus* zone, *Protoryctocephalus wuxunensis*-*Arthricocephalites intermedius* zone, and *Arthricocephalus chauveaui* zone. The Duyunian Stage has a rich trilobite fauna including four orders: Redlichiida, Agnostida, Corynex-

ochida, Ptychopariida. Further investigation of this trilobite fauna including their taxonomy, occurrences and phylogeny is needed. It will not only enhance the resolution of the biostratigraphic zonation and correlation in the uppermost Lower Cambrian, but also represent a potential candidate stage in global scale.

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