# Discovery and significance of *Naraoia* from the Qiandongian (lower Cambrian) Balang Formation, Eastern Guizhou, South China

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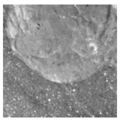

*Naraoia* is a taxon represented by commonly non-mineralized fossil found in lower–middle Cambrian strata and widely distributed in China, North America, and is an important component of Burgess Shale-type biotas. Well-preserved representatives of *Naraoia* are known from the Chengjiang and Kaili biotas of South China. Here, we report a new species of *Naraoia*, *Naraoia taijiangensis* sp. nov. from the Balang Fauna, Guizhou, South China. The new species clearly represents an intermediate morphology between *Misszhouia longicadata* and *N*. cf. *N. compacta.* It is obvious that there is a body-morphologic evolution for *Naraoia* from the Cambrian Series 2 to Cambrian Series 3 (lower Cambrian to the middle Cambrian). *N. taijiangensis* sp. nov. provides new data about evolution and geographical range of this genus. • Key words: *Naraoia*, Balang Formation, Qiandongian (lower Cambrian), Geyi, Taijiang, China.

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*Naraoia* is a taxon represented by commonly non-mineralized fossil found in lower–middle Cambrian strata and widely distributed in China, North America (Walcott 1912, Zhang & Hou 1985, Zhao *et al.* 1999, Steiner *et al.* 2005). The dorsal sclerotised area of representatives of *Naraoia* is subdivided two distinct parts, a cephalic shield and a posterior shield. The genus ranges from Cambrian Series 2 to late Silurian in age (Walcott 1912, Zhang & Hou 1985, Lin 2006, Zhang *et al*. 2007, Caron *et al*. 2004). Based on material from the middle Cambrian (Series 3) Burgess Shale of Canada, North America, Walcott (1912) described the type species of *Naraoia*, *Naraoia compacta* and specially erected the family Naraoiidae as different from common trilobites. Walcott (1931) described a second species of *Naoroia, N. spinifer* from Burgess Shale. Simonetta & Delle Cave (1975) described other two additional species *N. pammon* and *N. halia* from the Burgess Shale. Whittington (1977) restudied specimens of Walcott's collections and new specimens in detail, and concluded that two species, *N. pammon* and *N. halia* described by Simonetta & Delle Cave, are invalid, and recognized *Naraoia* as an unusual trilobite lacked thoracic segment. Robison (1984) reported *Naraoia compacta* from the lower Cambrian Gibson Jack Formation of Idaho and the middle Cambrian Marjum Formation of House Range, Utah, North America and approved the synonyms of Whittington. Zhang & Hou (1985) reported two species of *Naraoia*, *N. longicaudata* Zhang & Hou, 1985 and *N. spinosa* Zhang & Hou, 1985 from the lower Cambrian Chengjiang Biota of Yunnan, China. *N. longicaudata* was transferred to newly erected taxon, *Misszhouia longicaudata* by Chen *et al*. (1997). Sequentially, *N.* sp. from the Cambrian Emu Bay Shale, Kangaroo Island, South Australia (Nedin 1999), *N.* cf. *N. compacta*, *N.* sp. from the middle Cambrian Kaili Biota of Guizhou, China (Zhao *et al.* 1999), and *N.* cf. *N. longicaudata* and *N. spinosa* from the early Cambrian Niutitang Biota of Guizhou, China (Steiner *et al*. 2005) were reported. Then, the new study indicates that *N.* sp. from Emu Bay Shale is undiagnosis (Patterson *et al*. 2010). Due to its widespread occurrence in various *Lagerstätten*, *Naraoia* is an important soft-bodied component of Burgess Shale-type biotas. Fossils of *Naraoia* from three biotas of Chengjiang, Kaili, and the Burgess Shale are well-preserved, with alimentary diverticulae in the cephalic area and the alimentary canal in the axial area readily observed by the naked eye (Zhang & Hou 1985, Briggs *et al*. 1994, Hou *et al*. 1999, Zhao *et al*. 2005, Lin 2006). Caron *et al.* (2004) described *N. bertiensis* from the upper Silurian the Bertie

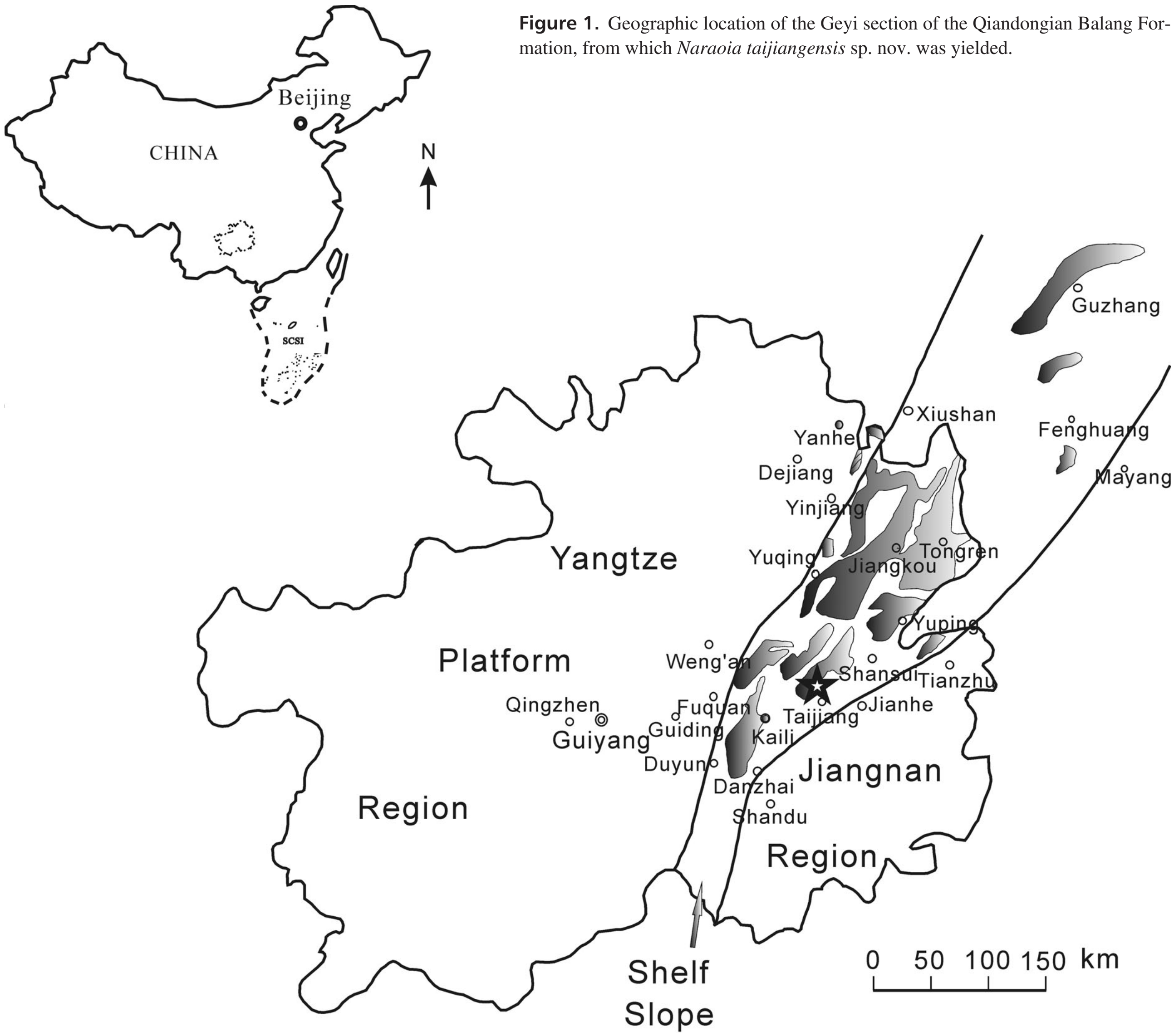


**Figure 1.** Geographic location of the Geyi section of the Qiandongian Balang Formation, from which *Naraoia taijiangensis* sp. nov. was yielded.

Formation, southern Ontario, Canada. Based on detailed examination for naraoiid material of Burgess and Chenjiang biotas, *N. halia* was been valid again by Zhang *et al.* (2007). As the result, *N. compacta*, *N. spinifer*, *N. spinosa*, *N. halia*, *N. bertiensis* were recognized as valid (see Caron *et al*. 2004, Zhang *et al*. 2007); *N. longicaudata* was referred to *Misszhouia longicaudata* (Chen *et al*. 1997), and *N. pammon* was recognized as a synonym of *N. compacta* (Whittington 1977, Robison 1984). Here we report a new species of *Naraoia* from the early Cambrian Balang Formation, Geyi Town, Taijiang County, Guizhou Province, China. The middle-upper part of the Balang Formation in Eastern Guizhou contains a diverse fossil assemblage known as the Balang Fauna (Peng *et al*. 2005). The Balang Fauna includes representatives of seven major groups, including porifer-chanceleoriids, cnidaries, priapulids, brachiopods, echinodermates, molluscs and arthropods, as well as many trace fossils (Peng 2009). Eocrinoids and trilobites are the most common taxa, and are characteristic members of the Balang Fauna. The very fossiliferous Geyi section of the Balang Formation in Geyi Town, Taijiang County contains the best examples of the Balang Fauna. The new species of *Naraoia* occurs in upper-middle part of Balang Formation of Geyi Town, Taijiang County, in association with other important components of Balang Fauna, *Guizhoueocrinus yui* Zhao *et al.*, 2007, the priapulid-worm *Hadomopanella*, corynexochid trilobites, as well as other fossils (Figs 1, 2). The discovery of the non-mineralized taxon of new species of *Naraoia* in the Balang Fauna indicates that the Balang Fauna also is a diverse Burgess Shale-type biota from Qiandongian (Cambrian Series 2) of China. The Balang Fauna is intermediate in age between the Chengjiang and Kaili biotas. Many taxa found in the Chengjiang Biota and Balang

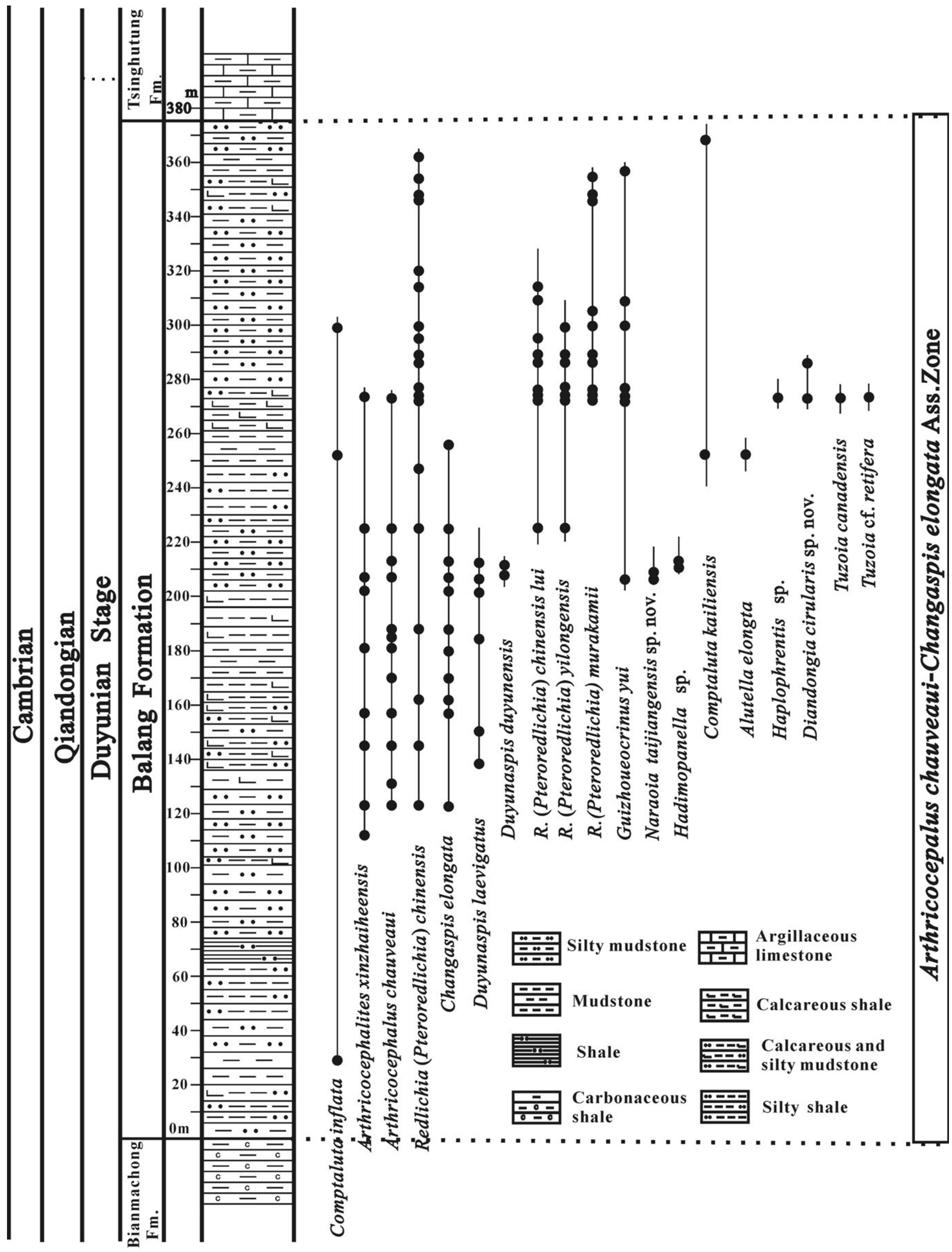


**Figure 2.** Fossil distribution in the Geyi section of the Qiandongian Balang Formation.

Fauna also range into the Kaili Biota (Zhao *et al.* 2002, 2005). For example, *Chancelloria* Walcott, 1912; *Isoxys* Walcott, 1890; *Naraoia* Walcott, 1912, occur in all three biotas. *Lingulellotreta* Rong, 1974 and *Diandongia* Rong, 1974 originally described from Chengjiang Biota are also present in the Balang Fauna (Peng *et al.* 2010a). This indicates that the Balang Fauna represents a transitional step between the Chengjiang and Kaili biotas.

## Geological setting and stratigraphy

The Balang Formation is mainly limited to a Cambrian outcrop belt in eastern Guizhou Province and western Hunan Province (Zhou *et al.* 1979; Yin 1987, 1996; see Fig. 1). The lower part of the Balang Formation is composed of gray-greenish to yellow-greenish clayey shale, while the upper part is composed of light gray calcareous shale and silty shale with intercalations of thin-bedded argillaceous carbobates. In general, the Balang Formation from its bottom to its top represents a shallowing-upwards sequence. The formation ranges widely in thickness from 100 m to more than 658 m (Yin 1987). Commonly, the Balang Formation is more than 600 m thick in central eastern Guizhou and commonly more than 300 m thick in northern Guizhou.

Zhou *et al.* (1980) and Yin (1987, 1996) proposed the biostratigraphic framework for the Balang Formation

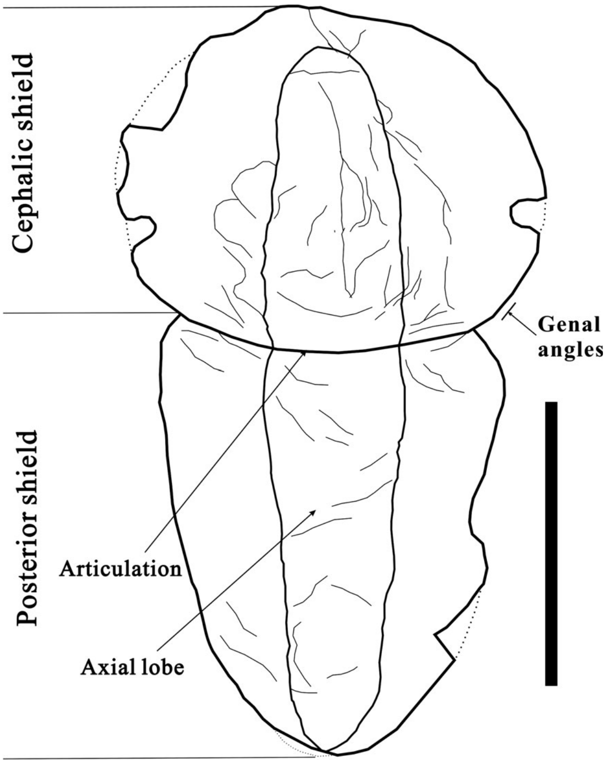


**Figure 3.** Drawing showing morphological terminology for *Naraoia taijiangensis* sp. nov., No. GY-172-56, scale bar = 5 mm.

based on trilobites, and considered the entire unit to correspond to the *Arthricocephalites-Changaspis-Balangia* Assemblage Zone or the *Arthricocephalus-Changaspis* Assemblage Zone. Based on heterochronic evolution of species of *Arthricocephalus* Bergeron, 1889, Yuan *et al.* (2001, 2006) revised this biostratigraphic subdivision and distinguished two separate zones, with the *Arthricocephalus jiangkouensis-A. granulus* Assemblage Zone in lower part of the Balang Formation and with the *Arthricocephalus chauveaui* Zone in the upper level of the formation. According to recent revision of biostratigraphy of the Balang Formation in eastern Guizhou, the *Arthricocephalus chauveaui-Changaspis micropyge* Assemblage Zone was separated by Peng (2009). Recently, the taxonomy of *Changaspis micropyge* has been discussed by Qin *et al.* (2010) and *Changaspis micropyge* was recognized as a synonym of *Changaspis elongata.* The Balang Formation belongs to the *Arthricocephalus chauveaui-Changaspis elongata* Assemblage Zone (Qin *et al.* 2010). Characteristically, the middle-upper parts of this Zone contain abundant *Redlichia* (*Pteroredlichia*) *chinensis*. *Arthricocephalus chauveaui*, *Changaspis elongata* are known in the lower Cambrian Henson Gletscher Formation of Greenland; the latter was deseribed as *Lancastria plana* by Blaker & Peel (1997, pp. 118–122, figs 69/2, 3, 70, 71/4, 5). In addition, *Arthricocephlites taijiangensis,* which is common in the Balang Formation, was assigned to *Hailiplaktos jishouensis* by Blaker & Peel (1997, figs 64/5–7). However, according to the correlation using three genera of corynexochid trilobites, the Balang and Henson Gletscher formations are equivalent in age. The Balang Formation is early Cambrian to late Tsanglangpuan in age, equivalent to the early Duyunian of the Cambrian stratigraphic system in slope facies (Peng & Babcock 2001). According to the criteria for correlation in South China, the Balang Formation is equivalent the Wulongqing Formation of Yunnan Province in age (Luo *et al.* 2008, Peng *et al.* 2010b). The upper part of the Balang Formation contains abundant *Redlichia* (*Pteroredlichia*) *chinensis* Walcott, 1905, and is correlated with the lower part of the Ordian of the Cambrian of Australia (Öpik 1970), that is, the position of the Balang Fauna correlates with those of the Guanshan Fauna and Emu Bay Shale Fauna (Nedin 1995, Luo *et al*. 2008, Hu *et al*. 2008, Peng *et al*. 2010a, b).

The Balang Fauna occurs in the upper part of the Balang Formation near Kaili City, Guizhou Province (Peng *et al*. 2006, 2007, 2010a, b), however, recent field work show presence of fauna in the middle to upper part of the formation at Jianggu town (Zhengyuan County), at Geyi town (Taijiang County), and at Jiaoban village (Jianhe County, eastern Guizhou Province). The Balang Formation is 375.4 m thick at the exposure near Geyi Town, Taijiang County, Guizhou Province, where the Balang Fauna assemblage occurs in the middle and upper parts of the formation. Up to now, *Naraoia* have been described only from the Geyi section, being associated with other components of Balang Fauna, *e.g. Guizhoueocrinus yui* Zhao *et al.*, 2007, the palaeoscoleid *Hodmopanella* sp., the trilobites *Arthricocephalus chauveaui* and *Changaspis elongata etc.* (Fig. 2).

All described specimens are deposited in the Palaeontological Museum of Guizhou University, Guiyang, China (GU). All specimens in the collection come from the Balang Formation, Geyi Town of Taijiang County, the prefix GY assigned to specimens indicates the Geyi section.

## Systematic palaeontology

*Remarks*. – Terminology used herein is explained in Fig. 2.

Phylum Arthropoda Siebold & Stannius, 1845
Class uncertain
Order Nectaspidida Raymond, 1920
Family Naraoiidae Walcott, 1912

**Genus *Naraoia* Walcott, 1912**

*Type species*. – *Naraoia compacta* Walcott, 1912.

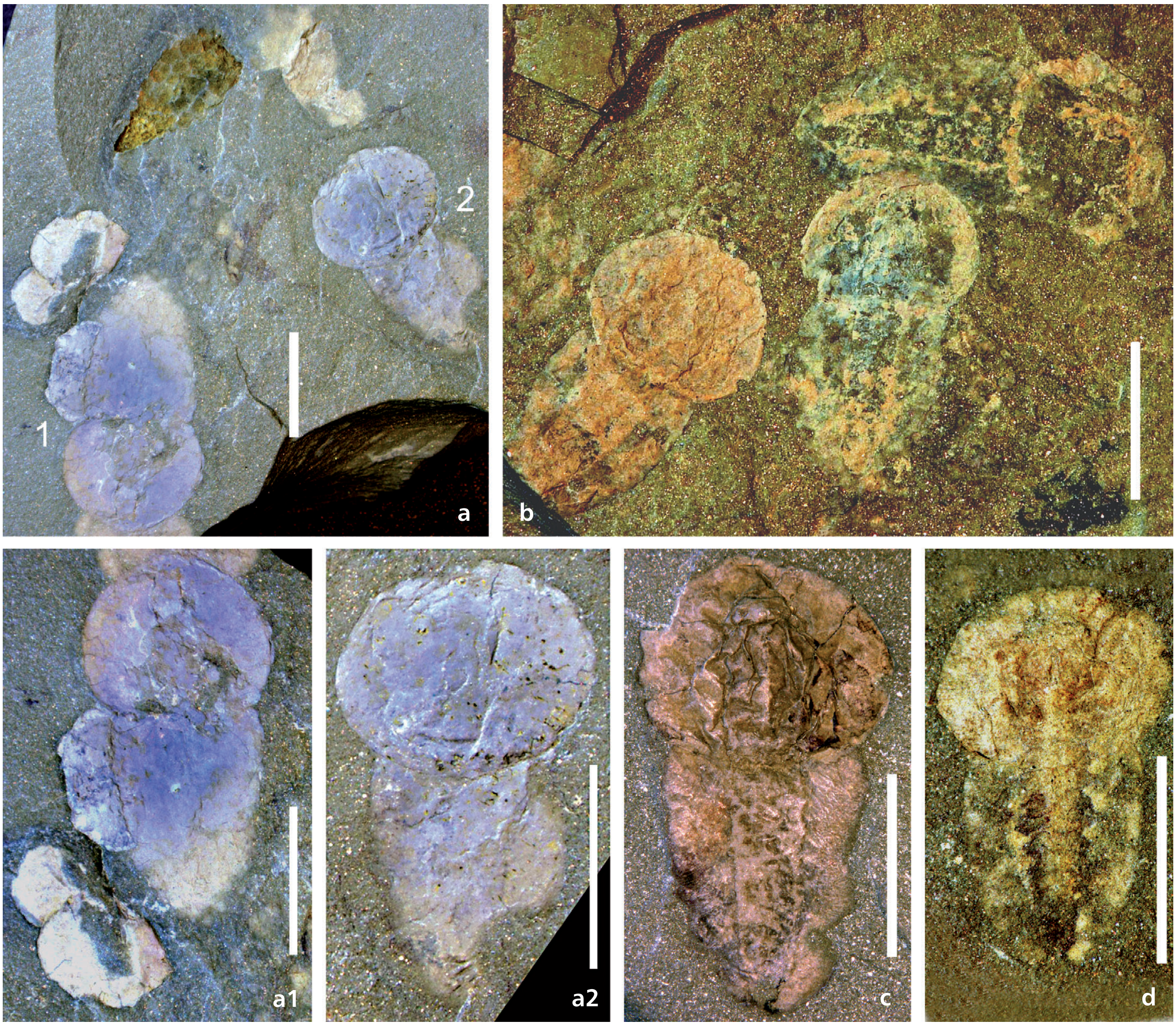


**Figure 4.** *Naraoia taijiangensis* sp. nov. from the Geyi section of Qiandongian (lower Cambrian) Balang Formation, Geyi town, Taijiang County, Guizhou Province, South China. • a – three–four dorsal exoskeletons preserved in association with *Guizhoueocrinus yui* Zhao *et al*., 2007, No. GY-172-14. • a1 – enlargement 1 of fig. a. • a2 – enlargement 2 of fig. A. • b – three complete dorsal exoskeletons, axial lobes can been seen clearly, paratype, No. GY-172-58. • c – a complete dorsal exoskeleton, axial lobe can been seen clearly, holotype, No. GY-172-56a. • d – a dorsal exoskeleton, juvenile specimen, abdomenal view, the coax (basis) of 8 paired bilateral axis appendages in posterior shield can been seen clearly, No. GY-178-57a. Scale bars = 5 mm.

*Diagnosis*. – A dorsal exoskeleton divided by a single transverse articulation into two shields, a cephalic shield and a posterior shield. The cephalic shield is round to half-round in dorsal view, devolving spinose or nonspinose in genal angles, both lateral margins and rear margin of posterior shield; one pair of lateral project antennas in anterior cephalic area. Axial lobe weak, both lateral axial lobe with alimentary system, including alimentary diverticulae and alimentary canal, with appendages in abdominal region.

*Occurrence and horizon*. – Canada and America, South China; early Cambrian to upper Silurian.

***Naraoia taijiangensis*** **sp. nov.**
Figures 3, 4a1–d

*Holotype*. – A dorsal exoskeleton preserved in slab of shale (GY-172-56a, Figs 3, 4b, c); cephalic shield 5.84 mm in length, and 7.07 mm in width. The cephalic axial lobe 4.45 mm in length, *ca* 2.3 mm in width. Posterior shield 7.30 mm in length, and 5.67 mm in width. The axial lobe 6.76 mm in length, *ca* 2.3 mm in width.

*Paratype material*. – Three dorsal exoskeletons preserved in slabs of shale (GY-172-58, Fig. 3, 4b), axial region can be seen clearly.

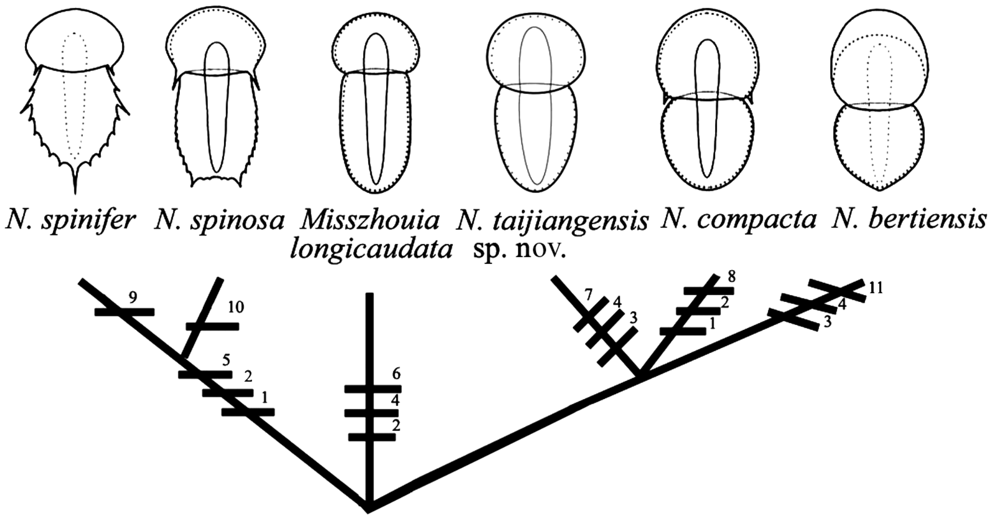


**Figure 5.** Phylogenetic position of every species between *Naraoia* and *Misszhouia*. Numbers refer to derived characteristics as follows: 1 – genal spines; 2 – subcircular cephalic shield, 3 – circular cephalic shield, 4 – round genal angle, 5 – with marginal spines of the posterior shield; 6 – elongate posterior shield, 7 – long elliptic posterior shield, 8 – wide elliptic posterior shield, 9 – single spine of the posterior shield rear margin; 10 – one pair spines of posterior shield rear margin; 11 – wide doublure (based on Caron *et al.* 2004, fig. 5, modified).

*Material.* – 8 specimens preserved in slabs of shale, and 3 additional counterpart molds.

*Etymology.* – The species is named for its occurrence in Taijiang County.

*Diagnosis.* – A species of *Naraoia* characterized by a nearly circular cephalic shield, round genal angle, and a posterior shield nearly long oval and the maximum width lie on anterior part; without spines in lateral and rear margins of cephalic and posterior shields; axial lobe crassitude in cephalic shield and the posterior shield, and quickly pointed near the rear margin (see Fig. 5).

*Description.* – Specimens from the Geyi section of the Balang Formation all show the same pertinent features, characterized by a nearly circular cephalic shield, round genal angles, lateral project antennal (Fig. 4d), and a posterior shield that is nearly long oval in outline, the width of posterior shield slightly narrower than that of cephalic shield, the maximum width lie on anterior part and generally tapers backward, showing a long elliptic posterior margin and no marginal spines; axial lobe crassitude in cephalic and the posterior shields. Articulated cephalic and posterior shields are preserved in dorsal aspect and are slightly convex, with patencial overlay area. The axial lobe in the cephalic shield is slightly convex, short, and club-shaped, and slightly wider in median part of the shield, tapering forward, with wrinkles on the surface. The axial lobe in the posterior shield is an elongate column with a smooth surface, and quickly pointed near the rear margin. According to one juvenile specimen (Fig. 4d) there are coax (basis) of 8 paired bilateral axis appendages in posterior shield abdomenal region. Length/width ratio of the posterior shield ranges from 1.28 to 1.3. No traces of appendages or soft internal anatomy are preserved.

*Comparison.* – The new species is similar to *N.* cf. *N. compacta* from the middle Cambrian Kaili Biota (Zhao *et al.* 2005, p. 755, pl. III, fig. 13) and *N. compacta* from Burgess Biota (Walcott 1912, pp. 175–177, pl. 28, figs 3, 4; Whittington 1977, figs 5–8, 79), however, the posterior shields of both latter species exhibit a maximum width located in the medial part of the shield, forward anterior and posterior slightly curved into a wide ellipse, in additional, *N. compacta* with genal spines in cephalic shield, even those without genal spines (Zhang *et al.* 2007, pp. 6, 7, fig. 3/1; fig. 4/1, 3–5) showing length/width ratio of the posterior shield *ca* 1.0, differ separately from new species. In addition, the new species exhibits characteristics for round genal angles, a long elliptic posterior margin of the posterior shield and no marginal spines are completely different from *N. spinifer*, *N. spinosa* (morph A and B) (see Zhang *et al.* 2007, p. 19), and *N. halia* (see Fig. 5).

## Discussion

The new species also resembles *Misszhouia longicaudata* from the Chengjiang Biota, Yunnan, China in exoskeleton (Zhang & Hou 1985, p. 592, pl. I, figs 1, 2; pl. II, figs 2–4; pl. III, figs 1–4). It is known that *Misszhouia longicaudata* was separated from *Naraoia* by Chen *et al.* (1997) based on its antennule orientation, smaller cephalic caeca and gut, lanceolate distal expod lobe, and partial fusion of the expod and first endopodal podomere, and the close relationship to *Naraoia* in phylogenies is recognized. Easily compared with *Naraioa*, the characters of *Misszhouia* are elongated posterior shield and caeca restricted to axial region (see Zhang *et al.* 2007, p. 31). Although no traces of soft internal anatomical characters of circular cephalic shield were found, lateral project antennal (Fig. 4d), the axial lobe crassitude, and fewer appendages in posterior shield of new species are more similar to that of *Naraoia.*

Even juvenile specimens of *M. longicaudata* (see Zhang *et al.* 2007, fig. 36/2, 3) showing 16–18 pairs of appendages beneath posterior shield, and length/width ratio of the posterior shield ranges 1.65 to 2.1 (Zhang *et al*. 2007, fig. 16), completely differ from that of new species. New species should be attributed to *Naraoia.* According to Zhang *et al.* (2007) detailed study, 2 species of *Naraoia*, *N. spinosa* and *N. compacta*, are more complicated in morphology, which *N. spinosa* with genal and margin spines shows morph A and lack marginal spines of posterior shield shows morph B (Zhang *et al.* 2007). The latter is some similar to the new species, but possesses characteristics of the genal spines and wide elliptic posterior shield obviously distinguishing from the new species. *N. compacta* without genal spines, original described *N. pammon* also has wide elliptic posterior shield and length/width ratio *ca* 1 obviously distinguishing from new species (see Fig. 4). *N.* cf. *compacta* from the middle Cambrian Kaili Biota (Zhao *et al.* 2005; Lin 2006, figs 2, 3) most characters are similar to the type species of *Naraoia*, *N. compacta*. *Naraoia* has been as an unusual trilobite lacking thoracic segment (Walcott 1912, Raymond 1920, Whittington 1977, Conway Morris 1979, Robison 1984, Zhang & Hou 1985).

*M. longicaudata* and *N. spinosa* from the Chengjiang Biota lie in *Eoredlichia* Zone (Cambrian Series 2) (Zhang *et al*. 2007), *N.* cf. *N. compacta* from the Kaili Biota lie in *Oryctocephlus indicus* Zone (Cambrian Series 3), and new species lies in *Arthricocephalus chauveaui-Changaspis elongata* Assemblage Zone (Cambrian Series 2, some later than *Eoredlichia* Zone). The new species clearly represents an intermediate morphology between *Misszhouia longicaudata* and *N.* cf. *N. compacta.* It is obvious that there is a body-morphologic evolution for *Naraoia* from the Cambrian Series 2 to Cambrian Series 3 (lower to middle Cambrian). New taxonomic information of *Naraoia* provides new data about evolution and geographical range of this genus.

*Occurrence and horizon.* – Geyi town, Taijiang County, Guizhou Province, South China; the Qiandongian (lower Cambrian) Balang Formation.

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