A restudy of *Oryctocephalus indicus* (Reed, 1910)*

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Abstract Restudy on morphology of *Oryctocephalus indicus* (Reed, 1910), based on specimens from Guizhou, China and Nevada USA, suggests that the subspecies regarded previously as *Oryctocephalus indicus indicus* (Reed, 1910), *O. indicus latus* Zhao et Yuan 2002, and *O. indicus kobayashi* Saito, 1934, are synonymous, and *Oryctocephalus americanus* Sundberg et McCollum, 2003 is a similar form of *O. indicus*. *Oryctocephalus indicus* is rediagnosed as having a glabella that is subconical in outline and tapering forward slightly; a thorax that comprises 12 segments, and a small pygidium that bears 2—3 axial rings with a terminal piece and a postaxial ridge. *Oryctocephalus indicus* is widely distributed in eastern Guizhou and ranges through a great interval of Kaili Formation. Its first appearance is almost identical with these events of trilobite extinction-recovery occurring at the end of the Early Cambrian, the alternation of acritach assemblages, the change of trace elements (REE) and stable isotopes (carbon) at the Wuliu-Zengjiaya section. As one of the key forms for defining the traditional Lower - Middle Cambrian boundary (the base of Cambrian Series 3 and Stage 5 in the new Cambrian chronstratigraphic standard), *O. indicus* has received detailed study and has more advantages than other species such as *Ovatoryctocara granulata* Tchemysheva, 1962 or *Arthricocephalus chauveaui* Bergeron, 1899.

Keywords: *Oryctocephalus indicus*, restudy, Kaili Formation, Cambrian, Guizhou, China.

Since both Chinese[1] and American Palaeontologists[2] proposed separately to mark the beginning of the Middle Cambrian based on the first appearance datum (FAD) of *Oryctocephalus indicus*[3] in the same year, the suggestion has been considered seriously and adopted frequently[4—18]. The International Subcommission on Cambrian Stratigraphy (ISCS) has organized the Working Group, chaired by L. B. McCollum, to select candidate sections that bear potential to become a GSSP for the traditional Lower-Middle Cambrian boundary (i.e. the base of Cambrian Series 3 and Stage 5 in the new Cambrian chronstratigraphic standard). During the 4th International Cambrian Symposium held in Nanjing recently, a decision on further investigation of both the evolution of oryctocephalids based on the material from Guizhou, China, and on the correlation between the Chinese and Siberian sections that contain oryctocephalids was made by ISCS. Following the decision, the authors worked once again on the *O. indicus*-bearing sections in eastern Guizhou. It turned out that the FAD of *O. indicus* occurs at 52.80 m above the base of the Kaili Formation at the Wuliu-Zengjiayan section[8,11], 31.33 m at the Miaobanpo section, 101.9 m at Nangao section, and 32.5 m at the Pingzhai section[8]. Of them, the Wuliu-Zengjiayan section is regarded as a candidate stratotype section for the *O. indicus* level. Although the FAD of *Arthricocephalus chauveaui* or *Ovatoryctocara granulata* has been proposed as the key species for a global Cambrian stage boundary[19,20], the proposal has received less supports. However, a number of colleagues preferred to adopt the FAD of *Oryctocephalus indicus* in defining the base of traditional Middle Cambrian Series or the base of both the Taijiangian Stage and the Wulingian Series in South China[8,15,17,21—28]. This paper aims to clarify the concept and stratigraphic range of the species *Oryctocephalus indicus*.

1 The key features of *Oryctocephalus indicus* (Reed, 1910)

Diagnosis provided by Jell and Hughes[29], Sundberg and McCollum[2], and Yuan et al.[8] are

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more or less different, involving the cranidial and pygidial characters of *Oryctocephalus indcus* (Fig. 1 (a), (c), (e)—(f), (h)—(j)). Abundant specimens of the species from the Kaili Formation of Guizhou indicate that the glabella of the species is in fact varied from subconical to subcylindrical in shape, but tapered slightly forward[29, 30], and the pygidium is micropygous with two or three axial rings, a terminal piece, and two or three pairs of marginal spines that are directed posteriorly[2, 8].

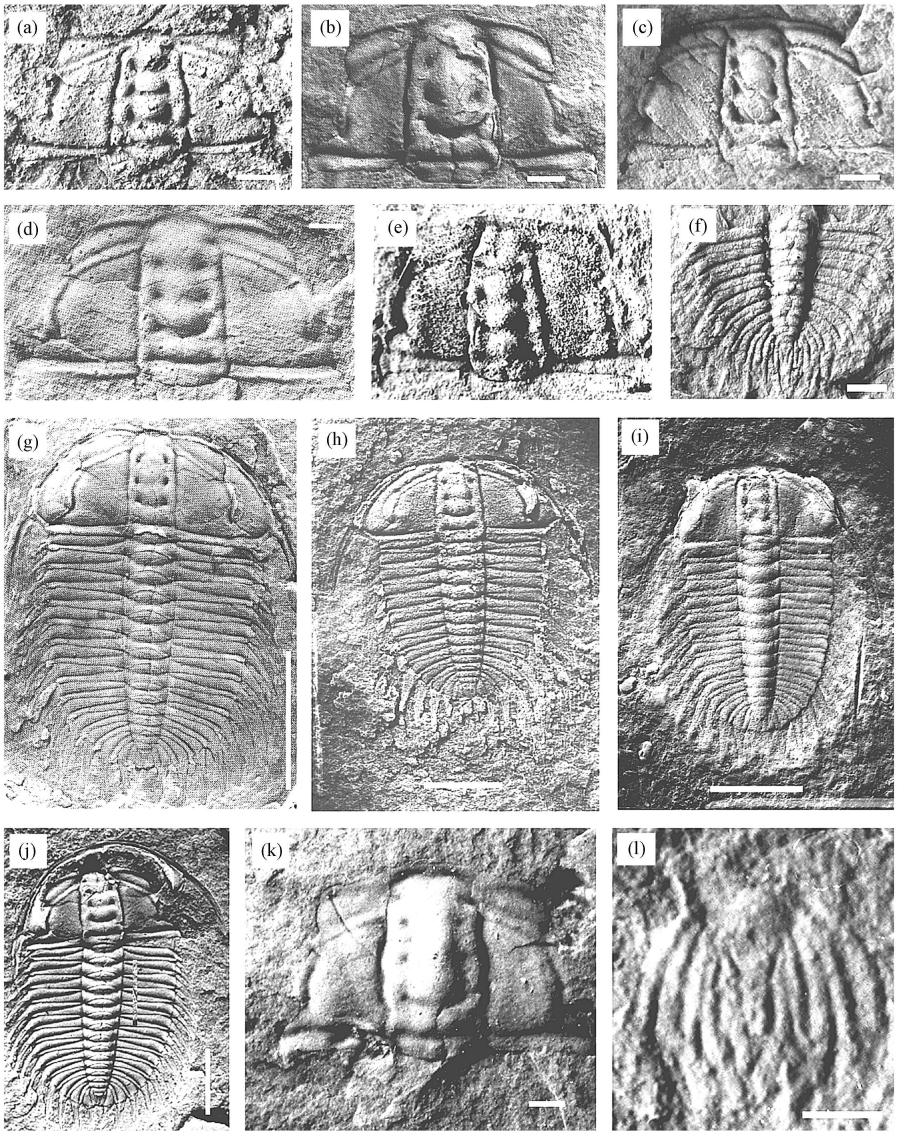

Fig. 1. *Oryctocephalus indicus* (Reed, 1910) and *Oryctocephalus americanus* Sundberg et McCollum, 2003 from Kaili Formation of Guizhou Province, China and the Emigrant Formation of Nevada, American. (a)—(k), *Oryctocephalus indicus* (Reed, 1910). (a) Cranidium, USNM4108034; (b) Cranidium, P4-2-120, formerly as *O. indicus indicus* in Yuan et al., 2002, pl. 20, fig. 5. (c) Cranidium, USNM4108055; (d) Cranidium, GTB-17-1-121, formerly as *O. indicus latus* in Yuan et al., 2002, pl. 20, fig. 4; (e) Cranidium, specimen USNM 4108019; (f) Incomplete thorax and pygidium, specimen 52; (g) Dorsal exoskeleton, GTBM-9-5-3131, formerly as holotype of *O. indicus latu* in Yuan et al., 2002, pl. 21, fig. 1; (h) Dorsal exoskeleton, GTBM-9-4. (i) Dorsal exoskeleton, GTBM-16-40; (j) Dorsal exoskeleton, GTBM-9-4-1300. (k)—(l) *Oryctocephalus americanus* Sundberg et McCollum, 2003. (k) Cranidium, USNM410808; (l) Pygidium, USNM41080103. Scale bars in (a)—(f), (k)—(l) equal 1 mm, and the other scale bars in (h)—(j) equal 5 mm.

2 Emendation of three subspecies of *Oryctocephalus indicus* (Reed, 1910)

Yuan et al. have divided *Oryctocephalus indicus* into three subspecies: *Oryctocephalus indicus indicus* (Fig. 1 (b))[8], *O. indicus latus* (Fig. 1 (d), (f))[8], and *O. indicus kobayashi*[2, 31] based mainly on their different numbers of marginal spines on the

pygidium, slightly different outlines of the glabella, and width of fixigena. However, close scrutiny and reexamination on most specimens reveal that these differences between 3 subspecies are very tiny and prove to be of intraspecific variance only on the one hand, and are commonly caused by deformation under shale preservation on the other hand. It is therefore considered to be unnecessary to divide *Oryctocephalus indicus* into subspecies.

3 Comparison with *Oryctocephalus americanus* Sundberg et McCollum, 2003

Based on the specimens from the Emigrant Formation in the Split Mountains and Goldfield Hills, Nevada, USA, Sundberg and McCollum erected a new species, *Oryctocephalus americanus* (Fig. 1(k)—(l))[5]. This species is mainly characterized by having the quadrate cranidium, the parallel-sided glabella with laterally restricted S_2—S_4, the moderately wide fixigenae, the twelve-segmented thorax, and the small pygidium with two axial rings and a terminal piece. Except for the minor difference in the glabellar shape, the more strongly isolated S_2—S_4, the cranidial features of *Oryctocephalus americanus* are similar to those of *Oryctocephalus indicus*. A close comparison of the morphological variation between specimens from Guizhou and Nevada reveals that the glabellar outline in both species is similar. Some speciemens from Nevada[5] bear subconical glabella. This type of glabella is also commonly seen in Chinese material[8].

4 Occurrence of *Oryctocephalus indicus* in the eastern Guizhou

The Kaili Formation is well developed in eastern Guizhou, South China. *Oryctocephalus indicus* commonly occurs in the Kaili Formation. Besides the Balang section in Taijiang (now Jianhe) County, the Yanying section and the Nangao section in Danzhai County, *O. indicus* was also recorded from the Zhusha section, Zhenyuan County, about 60 km east away from the Balang section, Taijiang (now Jianhe) County[8, 10, 11, 32]. At the four sections mentioned above, the thickness of the Kaili Fm. varies from 214 m to 326.2 m, and the stratigraphic interval of *O. indicus* ranges from 64.8 m to 87.59 m[8]. The *O. indicus*-bearing strata in eastern Guizhou is about 20 times thicker than that in the western United States[28]. Apparently, this suggests that both the Kaili Formation and the Emigrant Formation of Nevada were formed at quite different depositional rates.

5 Conclusions

Revised diagnosis of *Oryctocephalus indicus* is helpful to studying its taxonomy and stratigraphic correlation in the world. Furthermore, the restudy of *O. indicus* will enhance its advantage as a key species for defining a global stage and series boundary that correlates with the traditional Lower-Middle Cambrian boundary. In the Kaili area, eastern Guizhou, *O. indicus* is of common occurrence, wide distribution, and complete stratigraphic range. The first appearance datum of *O. indicus* is consistent with the events of the mass extinction-recovery occurrence in the traditionally terminal Early Cambrian[8, 9, 11, 21, 32]. Moreover, the turnover points of alternation of acritach assemblages, trace elements (REE), and stable isotopes (carbon)[13—18, 33] are also consistent with the FAD of *O. indicus* in the Wuliu-Zengjiaya section, Balang village, TaiJiang (now Jianhe) County and the Pingzhai section, Danzhai County. As one of the key forms for defining the base of the Global Cambrian Series 3 and Stage 5, *O. indicus* received detailed study and has considerable advantages against other species such as *Ovatoryctocara granulata* Tchernysheva, 1962 or *Arthricocephalus chauveaui* Bergeron, 1899.

6 Systematic palaeontology

Here, except for the prefix USNM deposited in the National Museum of Natural History of the United States, all other described specimens are deposited in the Palaeontological Museum of the Guizhou University, Guiyang, China (GU). Specimen having the prefix GTB is in the collection from Wuliuzenjiayan section of the traditional Lower-Middle Cambrian Kaili Formation at Balang village, Taijiang (now Jianhe) County, Guizhou Province; specimens having the prefix GTBM are in the collection from Miaobanpo section of Kaili Formation 1.2 km away from north Balang village; specimens having prefix P are the collection from Pingzhai section of the Kaili Formation at Pingzhai village, Taijiang (now Jianhe) County, Guizhou Province, China, and specimens having prefix USNM are in the collection the Emigrant Formation in the Split Mountain, Nevada.

Genus *Oryctocephalus* Walcott, 1886

Type species: *Oryctocephalus primus* Walcott, 1886

Oryctocephalus indicus (Reed, 1910)

Fig. 1((a)—(j))

1910 *Zacanthoides indicus* Reed, p. 9; pl. 1. fig. 15.

1910 *Oryctocephalus* cf. *O. reynoldsi* Reed, p. 12, pl. 1, figs. 22—24.

1934 *Oryctocephalus orientalis* Saito, (in part), p. 230—231, pl. 25, fig. 21.

1934 *Oryctocephalus kobayashi* Saito, p. 231—232, pl. 25, figs. 23—25.

1940 *Oryctocephalina reticulata* Lermontova, Лермонтова, стр. . 137, таб., 42, фиг. 3.[34].

1944 *Oryctocephalus indicus* (Reed, 1910), Kobayashi, p. 33[35].

1951 *Oryctocephalus* sp., 1, Rasetti, p. 193, pl. 9, fig. 24[36].

1962 *Oryctocephalus reticulates* (Lermontova, 1940), Чернышева, стр. 20—22, таб., II, фиг. 3, 5, 8[37].

1967 *Oryctocephalus indicus* (Reed, 1910), Kobayashi, p. 487, text-figs. 7, 11a—b[38].

1971 *Oryctocephalus reticulatus* (Lermontova), Чернышева, стр. l. 39, таб., 13, фиг. 10[39].

1974 *Oryctocephalus incurvus* Lu et Chien, Lu et al., p. 101, pl. 39, fig. 8[40].

1980 *Oryctocephalus* cf. *O. incurvus* Lu et Chien, Zhang et al., p. 270, pl. 96, figs. 13—15.

1983 *Oryctocephalops incurvus* (Lu et Chien, 1974), Lu & Qian, p. 26, pl. 3, figs. 6—7.

1983 *Oryctocephalops tongrenensis* Lu et Qian, p. 27, pl. 3, figs. 4—5[41].

1997 *Oryctocephalus indicus* (Reed, 1910), Jell & Hughes, p. 34—35, pl. 5, figs. 16—19, text-figs. 7A—C.

1997 *Oryctocephalus indicus* (Reed, 1910), Yuan et al., p. 496, pl. 4, figs. 1—6.

1997 *Oryctocephalus tongrenensis* (Lu et Chien), Yuan et al., p. 496, pl. 4, figs. 8—9.

1997 *Oryctocephalus indicus* (Reed, 1910), Sundberg & McCollum, p. 1073—1077, figs. 9-1—9-8, 9-10.

1999 *Oryctocephalus indicus* (Reed, 1910), Zhao et al., pl. 4, fig. 4[42].

1999 *Oryctocephalus indicus* (Reed, 1910), Yuan et al., p. 25, pl. 1, fig. 6[43].

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

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

2001c *Oryctocephalus indicus* (Reed, 1910), Zhao et al., pl. 6, fig. 1.

2002 *Oryctocephalus indicus indicus* (Reed, 1910), Yuan et al., p. 101, 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 indicus latus* Zhao et Yuan, Yuan et al., p. 101—102, pl. 20, figs. 2—3; pl. 21, figs. 1—3, 5, 6; pl. 22, figs. 2, 7, 8; pl. 28, figs. 9, 10.

2002 *Oryctocephalus orientalis* Saito, 1934, Yuan et al., p. 103, pl. 22, figs. 3, 4, 6.

2003 *Oryctocephalus indicus* (Reed, 1910), Sundberg & McCollum, p. 960—962, pl. 8, figs. 9, 12—13.

Holotype: Incomplete exoskeleton (pygidium plus partial thorax), GSI 9774[3,29] from horizon 2 of the Spiti area, India.

Additional material: 165 exoskeletons and 297 cranidia.

Revised diagnosis: Cranidium quadrate to subquadrate; glabella subcylindrical to subconical, slightly tapering forward, with 4 pairs of pit-like lateral furrows of which 1 to 3 transglabellar furrows, S4 pit-like, faint, near axial furrows; fixigena wide to moderately wide (0.63—1.20 of gllabellar width); palpebral lobe medium in length; librigena narrow with long genal spine; 12 thoracic segments with long, diagonal-directed marginal spine; small pygidium with 2—3 axial rings, and 2—3 pairs of pleural spines.

Description: elongately elliptical, small, micropygous 7—12 mm long. Exoskeleton; cranidium wide, subtrapezoidal, slightly arched forward anteriorly; glabella subcylindrical to subconical in outline, gently convex, rounded anteriorly, with four pairs of pit-like glabellar furrows, of which S4 near the axial furrow, S1 connected by shallow transverse furrows, S2 or S2 and S3 sometimes connected by shallow transverse furrow, S1—S3 sometimes connected shallow longitudinal furrow; Occipital ring slightly narrowing laterally; anterior border furrow distinct; preglabellar field absent; anterior border narrow,

gently convex, slightly arched forward; fixigena medium to wide (63—120% of glabellar width); palpebral lobe narrow, about 0.4 of glabellar length; eye ridge strong, slightly inclined from anterior end of palpebral lobe to axial furrow opposite S4; posterior border furrow distinct; anterior branch of facial suture slightly divergent from anterior end of palpebral lobe, then curving inward, posterior branch directed backwards; Librigena narrow (exs.), genal spine long, reaching at a level of fourth thoracic segment; 12 thoracic segments with long pleural spines; small pygidium with 2—3 axial rings, a terminal piece, a postaxial ridge, and 2—3 pairs of marginal spines directed posteriorly.

Occurrence: The Middle Cambrian; western United States, South China, eastern India or Himalayan area, North Korea, and Siberia[35].

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