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Global Standard Stratotype-Section and Point (GSSP) for the conterminous base of the Miaolingian Series and Wuliuan Stage (Cambrian) at Balang, Jianhe, Guizhou, China

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The International Commission on Stratigraphy and the IUGS Executive Committee have recently ratified a Global Standard Stratotype-section and Point (GSSP) defining the conterminous base of the third series and the fifth stage of the Cambrian System. The series and the stage are respectively named the Miaolingian Series and Wuliuan Stage, after the Maioling Mountains in southeastern Guizhou and the Wuliu sidehill, Jianhe County, in eastern Guizhou Province, South China, where the GSSP is located. The GSSP is exposed in a natural outcrop near the Balang Village at a position of 26°44.843'N latitude and 108°24.830'E longitude. It is defined at the base of a silty mudstone layer 52.8 m above the base of the Kaili Formation in the Wuliu-Zengjiayan section, coinciding with the first appearance of the cosmopolitan oryctocephalid trilobite Oryctocephalus indicus *(base of the* O. indicus *Zone). Secondary global markers at or near the base of the series and stage include the peak of a rather large negative carbon isotopic excursion (ROECE excursion), the simultaneous appearance of many acanthomorphic acritarch forms, a transgressive phase of a major eustatic event, and the last appearance of intercontinental polymerid trilobites, either* Bathynotus *or* Ovatoryctocara. *Faunal turnovers close to the base of the Miaolingian Series and Wuliuan Stage have been recognized as being at the base of the* Oryctocephalus indicus *Zone of Amgan Stage in Siberia, the Delamaran Stage in Laurentia, the* Oryctocephalus indicus *Zone in the Indian Himalaya and North Greenland, near the base of the Delamaran Stage in Australia, and within the* Eccaparadocides sdzuyi *Zone in Iberia and the* Ornamentaspis frequens *Zone in Morocco.*

Introduction

The International Subcommission on Cambrian Stratigraphy (ISCS) has recommended a subdivision of the Cambrian System into four series (Peng, 2004, 2006; Babcock et al., 2005; Peng et al., 2006; Babcock and Peng, 2007). Within each series it is expected that two or three stages will be recognized with their boundaries corresponding to horizons that can be precisely correlated with confidence through almost all palaeocontinents. Cambrian boundary positions ratified by the International Union of Geological Sciences (IUGS) and International Commission on Stratigraphy (ICS) (Figs. 1, 2) are: 1, the base of the Terreneuvian Series and Fortunian Stage, which is also the base of Cambrian System, Paleozoic Erathem and Phanerozoic Eonothern, corresponding to the base of *Treptichnus pedum* Zone in Newfoundland (Brasier et al., 1994; Landing, 1994; Gehling et al., 2001; Landing et al., 2007); 2, the base of Drumian Stage corresponding to the base of the *Ptychagnostus atavus* Zone in Utah, USA (Babcock et al., 2007); 3, the base of the Guzhangian Stage corresponding to the base of *Lejopyge laevigata* Zone in Hunan, South China (Peng et al., 2009a); 4, the base of the Furongian Series and Paibian Stage corre-

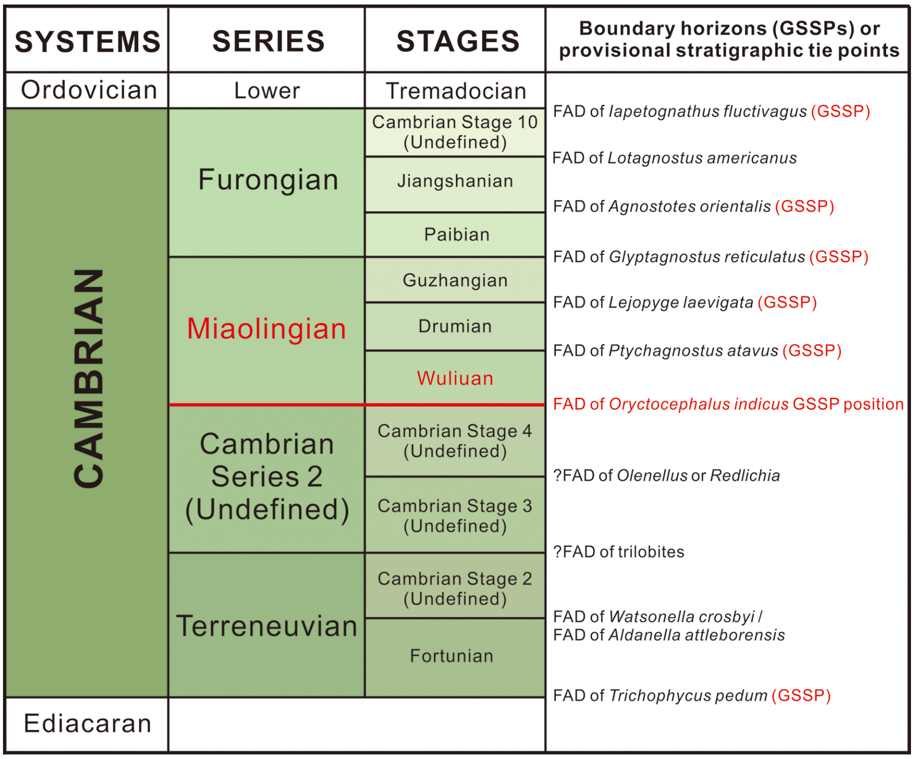

Figure 1. Chart showing working model for global chronostratigraphic subdivision of the Cambrian System, indicating the lower boundary of the newly ratified Miaolingian Series and Wuliuan Stage (modified from Peng et al., 2009a, 2012b).

sponding to the base of *Glyptagnostus reticulatus* Zone in Hunan, South China (Peng et al., 2004a); 5, the base of the Jiangshanian Stage corresponding to the base of the *Agnostotes orientalis* Zone in Zhejiang, Southeast China (Peng et al., 2012a); and 6, the base of Miaolingian Series and Wuliuan Stage, ratified recently, in Southwest China.

The purpose of this paper is to announce ratification of the GSSP for the conterminous base of the Miaolingian Series and the Wuliuan Stage, which coincides with the FAD of the intercontinental oryctocephalid trilobite *Oryctocephalus indicus*. The Miaolingian Series and the Wuliuan Stage are newly named Cambrian chronostratigraphic units, replacing in concept and content the provisional Series 3 and Stage 5 (Figs. 1, 2, 5, 7, 9). The GSSP for the base of the new series and new stage lies within Bed 9 at 52.8 m above the base of the Kaili Formation in the Wuliu-Zengjiayan section that is about 0.5 km North of Balang Village, Jianhe County, eastern Guizhou Province, South China (Figs. 3, 4). This point fulfills all of the geological and biostratigraphic requirements for a GSSP (see Remane et al., 1996). The section is easily accessible, and access for research is unrestricted. It is located within the Jianhe Natural Reserve of Paleontological Fossils and the Miaoling National Geopark, both have been under permanent protection by the government of Guizhou Province since the natural reserve was approved in 2002 and by the Ministry of Land and Mineral Resources of China since the geopark was approved in 2009.

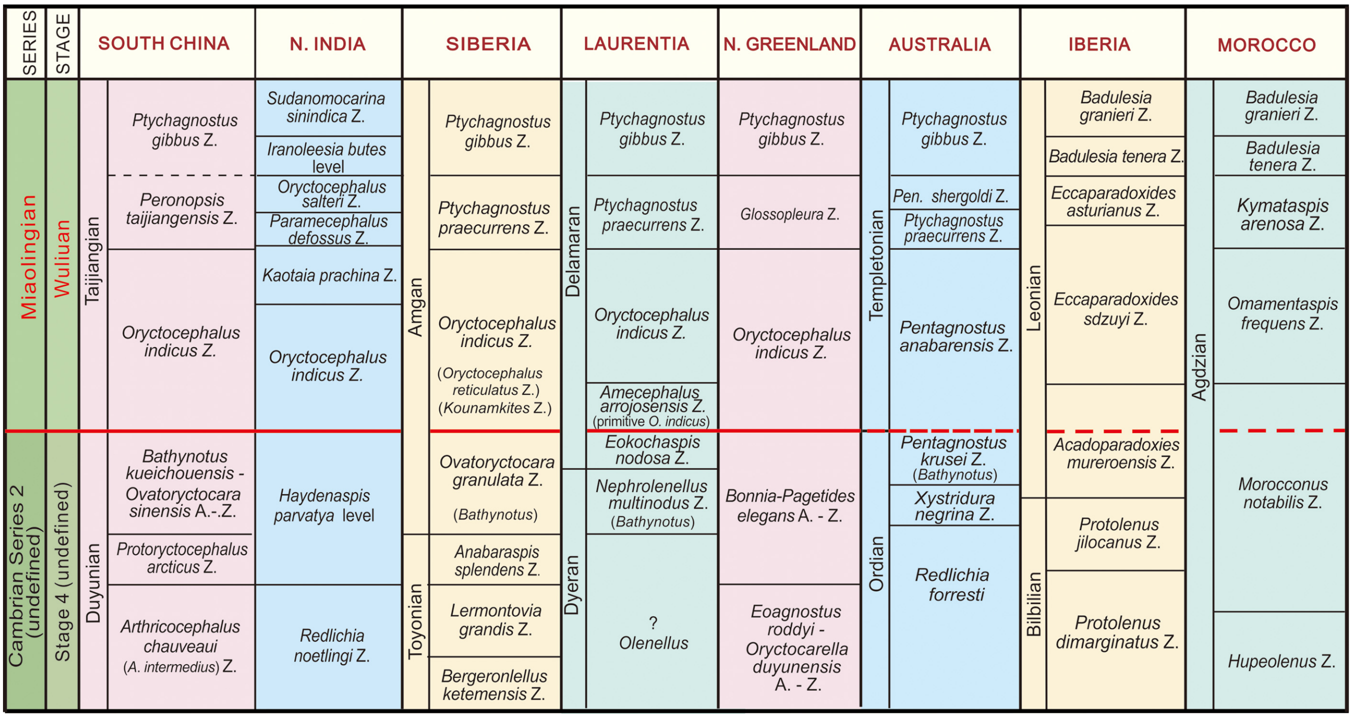

Figure 2. Correlation chart of the interval of Cambrian Stage 4 through Wuliuan Stage (Miaolingian Series). Chart compiled from numerous sources, summarized principally in Yuan and Ng. (2014), Geyer (2015), Zhao et al. (2015, 2017), Hughes (2016), Sundberg et al. (2016), Peng et al. (2017) and Esteve et al. (2017).

Stratigraphic Rank of the Boundary

The Miaolingian Series is the third series of the Cambrian System, and the Wuliuan Stage is the lowermost stage of the Miaolingian Series (Figs. 1, 2). The base of the series and stage defines automatically the top of provisional Cambrian Series 2 and its uppermost stage, the provisional Stage 4, both of which are unnamed yet. The boundary will be a standard series/epoch and stage/age GSSP. The upper boundary of the series is defined by the base of the Furongian Series, and the

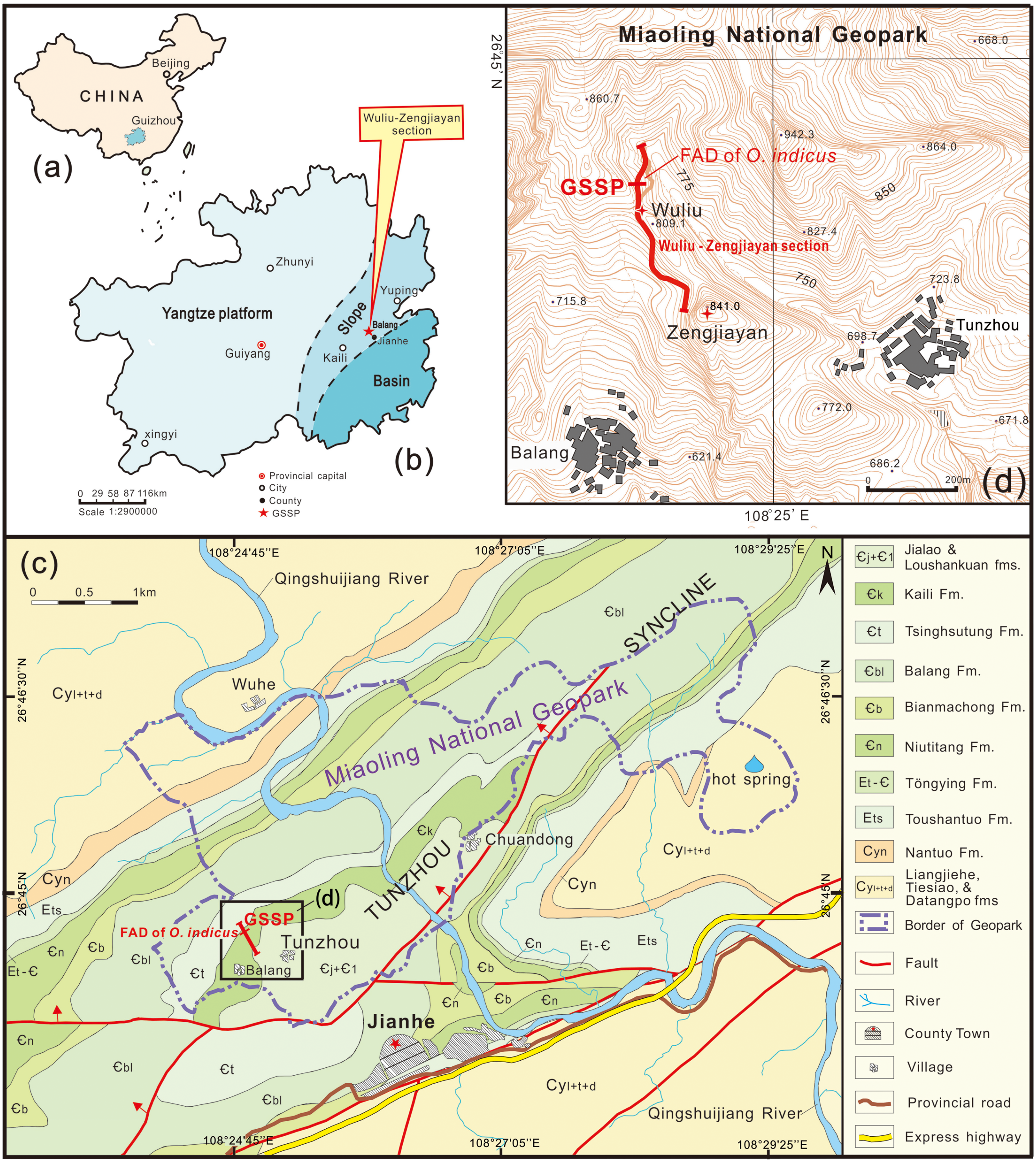

Figure 3. (a) Location of Guizhou in China (outlined blue area); (b) Cambrian palaeogeography of Guizhou with the Wuliu-Zengjiayan GSSP section indicated by a red star; (c) Geological map of the part of eastern Guizhou province, showing the study area and the location of the GSSP section for the Miaolingian Series and Wuliuan Stage (modified from Geological Survey of Guizhou Province, 1966); (d) Topographic map of the Balang and Tunzhou area, indicating location of the Wuliu-Zengjiayan GSSP section with the FAD of **Oryctocephalus indicus** *(red line; modified from topographic map G-49-37-55, Dagaowu Sheet, issued by Surveying and Mapping Bureaus of Guizhou and Shaanxi, 1991; 1:10000 sale); the Wuliu-Zengjiayan section is named after the Wuliu sidehill and Zengjiayan hill (indicted by red stars).*

upper boundary of the stage is defined by the base of the Drumian Stage of the Miaolingian Series (Fig. 1).

The names Wuliuan and Miaolingian are derived from geographic localities in eastern, where the GSSP is located, and southeastern Guizhou. The name of Wuliuan Stage (and Age) is derived from Wuliu, a side-hill that the Wuliu-Zengjiayan section crosses, and the name Miaolingian Series (and Epoch) is derived from the Miaoling Mountains, which traverse the southeastern part of the Guizhou Province. These mountains are inhabited primarily by the Miao ethnic minority.

Geography and Physical geology of the GSSP

Geographic Location

The Wuliu-Zengjiayan section (Yuan et al., 1997, 1999, 2002; Zhao et al., 2001a, b, 2004, 2007; 2012a, c) is exposed along a hill ridge, which is about 0.5 km northeast of Balang Village, Jianhe County (formerly the village was administered by Taijiang County), Guizhou Province, China (Fig. 3). The studied area lies in the southwest of the Miaoling National Geopark (Fig. 3(c)). The Balang Village is located 2.5 km from the township of Jianhe County, which is easily accessible via the Guiyang-Kaili-Yuping Express Highway. The position of the Wuliu-Zengjiayan section is on topographic map G-49-37-55, Dagaowu Sheet, 1:10000 sale (Fig. 3(d)). The GSSP is exposed near the ridge crest at a position of 26º44.843'N latitude and 108º24.830'E longitude at an elevation of approximately 795 m.

Geological Location

The Cambrian geology of eastern Guizhou, the site of the GSSP section, has been summarized in a number of papers, among which the most notable are the monographs on the Regional Geology of Guizhou Province published by the Guizhou Bureau of Geology and Mineral Resources (1987), and articles by Yin (1987), Yuan et al. (2002), and Zhao et al. (2011).

The Miaoling Mountains in southeastern Guizhou consist of a series of folds and thrust slices resulting from post-Devonian compressional tectonics that affected the area between the Duliujiang and Qingshuijiang river system of eastern Guizhou (Yin, 1987). The Balang area of Jianhe County, eastern Guizhou, is located on the northwestern limb of the Tunzhou Syncline (Fig. 3(c)), which belongs to the Shansui Composite Syncline in the Nanhua fold belt. The lower half of the Cambrian System in this area was deposited on the lower part of the Jiangnan Slope (mostly shale facies), which was located between the Yangtze carbonate platform to the northwest and deeper water facies of the Jiangnan Basin to the southeast (e.g., Yin, 1987; Peng and Babcock, 2001) (Fig. 3(b)). Exposure of Neoproterozoic and Cambrian strata in the Jianhe area is highly favorable. The Precambrian succession there consists of several formations, which, in ascending order, are the Liangjiehe, Tiesiao, Datangpo, Nantuo, Toushantuo (=Doushantuo), and Töngying (=Dengying) formations (the former three units are marked as Cy_{l+t+d} on Fig. 3(c)). The Cambrian succession in this area comprises seven units. In ascending order these are the Niutitang, Bianmachong, Balang, Tsinghsutung, Kaili, Jialao and Loushankuan (=Loushanguan) formations (Fig. 3(c)). Detailed descriptions of these units have been presented in a number of papers (Zhou et al., 1980; Yin, 1987; Pu and Ye, 1991; Zhao et al., 2001a, b). An overview of Cambrian paleogeography, biotic provinces, and geologic history of the region was provided by Peng and Babcock (2001).

The Kaili Formation is exposed widely in eastern and southeastern Guizhou, showing a SW–NE trend across the Danzhai, Taijiang, Jianhe, Zhenyuan and Yuping counties to the Tongren area. The Kaili Formation was deposited in an open-shelf to slope setting (Zhou et al., 1980; Zhang et al., 1996; Zhao et al., 2001a, b; Yuan et al., 2002; Gaines et al., 2011), where it overlies either the Wuxun Formation or the Tsinghsutung Formation and is overlain by the Jialao Formation (Figs. 4(a), 5). The formation is typically about 250 m thick, and straddles the boundary of the provisional Cambrian Series 2 and the Miaolingian Series. The Kaili Formation crops out extensively in the Balang and Chuandong areas (Fig. 3(c)), where it overlies the Tsinghsutung Formation in conformity. The Wuliu-Zengjiayan section contains strata extending from the top part of the Tsinghsutung Formation to the basal part of the Jialao Formation with the GSSP occurring in the lower part of the Kaili Formation. The Kaili Formation contains a total of 47 trilobite genera (subgenera) with 16 genera occurring below the GSSP level, 20 genera above, and 11 genera ranging through the boundary (Zhao et al., 2001a, b; Yuan et al., 2002). Trilobites are commonly articulated and thin shelled, indicating a relatively deep, quiet water sedimentary environment (Zhang et al., 1996; Zhu et al., 1999; Yuan et al., 2002; Gaines et al., 2011).

Location of Level and Specific Point

The boundary interval of the Wuliu-Zengjiayan section consists primarily of silty and calcareous mudstones (Fig. 5) that are abundantly fossiliferous and bear the first appearance datum (FAD) of the widely distributed oryctocephalid trilobite *Oryctocephalus indicus* (Fig. 6(a)–(d)), which is selected as primary marker to define the provisional Stage 5 of Cambrian by the International Subcommission on Cambrian Stratigraphy, at 52.8 m above the base of the Kaili Formation (Zhao et al., 2001a, b). The species *O. indicus* is associated with a large number of trilobites, such as *Pagetia*, *Euarthricocephalus*, *Burlingia* and *Olenoides*. Below GSSP level, the *Bathynotus kueichouensis– Ovatoryctocara sinensis* Assemblage-Zone is recognized (Figs. 4(a), 5, 6), which is characterized by the presence of many trilobites with broad geographic ranges, e.g. *Bathynotus*, *Redlichia*, *Oryctocephalops*, *Ovatoryctocara*, and *Oryctocephalites* (Yuan et al., 1997, 2002; Zhao et al., 2001a, b, 2007, 2012a, c; Sundberg et al., 2011; Fig. 6(e)–(h)).

Stratigraphic Completeness

Detailed bed-by-bed correlation of the Miaolingian strata through eastern Guizhou, coupled with detailed biostratigraphy (Yuan et al., 1997, 1999, 2002; Yin and Yang, 1999; Yang and Yin, 2001; Zhao et al., 2001a, b, 2004, 2005, 2007, 2012a, b, c, 2014, 2015, 2017; Yin et al., 2010; Sundberg et al., 2010, 2011), sedimentology (Zhang et al., 1996; Gaines et al., 2011), carbon isotope chemostratigraphy (Yang et al., 2003; Guo et al., 2005, 2010a, b), sulphur isotope chemostratigraphy (Guo et al., 2014) and biomarkers (Wang et al., 2014) clearly demonstrate the stratigraphic continuity of the basal interval of the Wuliuan

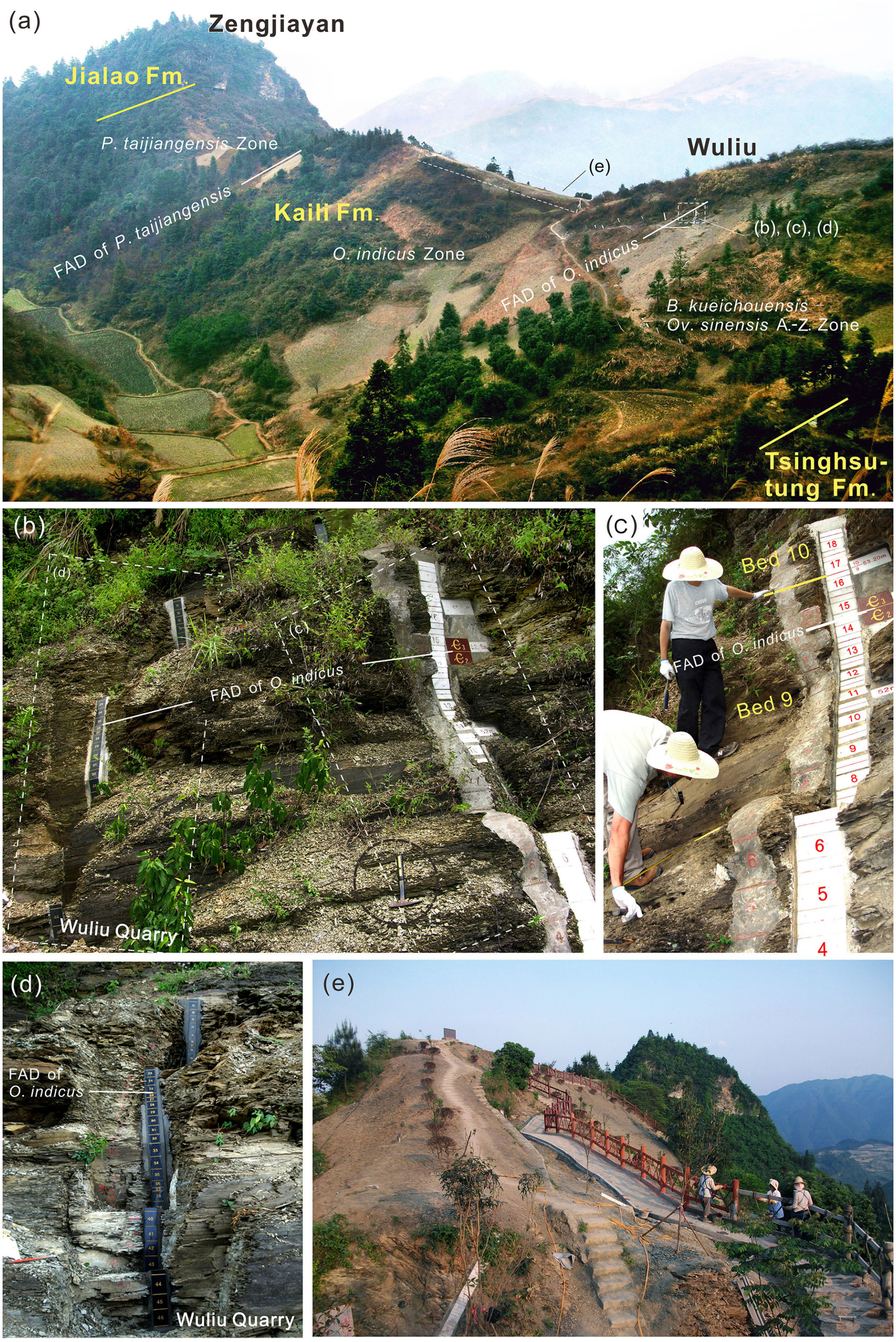

Figure 4. Exposure of the Wuliu-Zengjiayan GSSP for the base of the Wuliuan Stage (coinciding with the FAD of **Oryctocephalus indicus** ***in the Kaili Formation?near Balang, Jianhe County, Guizhou Province, South China. Strata underlying the Wuliuan GSSP belong to the upper part of undefined Cambrian Stage 4 of provisional Series 2. (a) View of the Wuliu-Zengjiayan section showing three trilobites zones of the Kaili Formation; (b) The boundary interval of the GSSP in Wuli-Zengjiayan section, showing the FAD of*** **O. indicus** ***in the lower part of the Kaili Formation; (c) and (d) close-up views of the rectangle areas in (b). (c) Showing the bed numbers in yellow (Bed 9 and 10), the numbers of collecting interval in red on the white marble, and the FAD of O. indicus, which lies at 52.8 m above the Kaili Formation and defines the base of Wuliuan Stage; (d) The "Wuliu Quarry", studied by Sundberg et al. (2011), with identical succession and fossil ranges as the Wuliu-Zengjiayan GSSP section; (e) Partial outcrop of the*** **O. indicus** ***Zone, where the rocks yield the Kaili Biota, along with a walk terrace leading to the GSSP site.***

Stage (Miaolingian Series) in the Wuliu-Zengjiayan section. Biostratigraphic studies of eastern Guizhou and other countries have revealed a consistent succession of trilobite species and acritarch taxa (e.g., Tchernysheva, 1962; Zhang et al., 1980; Whittington, 1988, 1995; Astashkin et al., 1991; Moczydłowska, 1991; Palmer and Repina, 1993; Jell and Hughes, 1997; Yuan et al., 1997, 2002; Sundberg and McCollum, 1997, 2003; Palmer, 1998; Hughes and Jell, 1999; Yin and Yang, 1999; Sundberg et al., 1999, 2011; Shergold and Whittington, 2000; Yang and Yin, 2001; Korovnikov, 2001, 2006; Zhao et al., 2001a, b, 2004, 2007, 2012a, b, 2014, 2015; Geyer, 2005; Fletcher, 2007; McCollum and Sundberg, 2007; Shabanov et al., 2008; Kruse et al., 2009; Peng et al., 2009b; Yin et al., 2009, 2010; Moczydłowska and Yin, 2012; Hughes, 2016; Singh et al., 2016; Sundberg et al., 2016) as observed in the Wuliu-Zengjiayan section. This section is interpreted to represent continu-

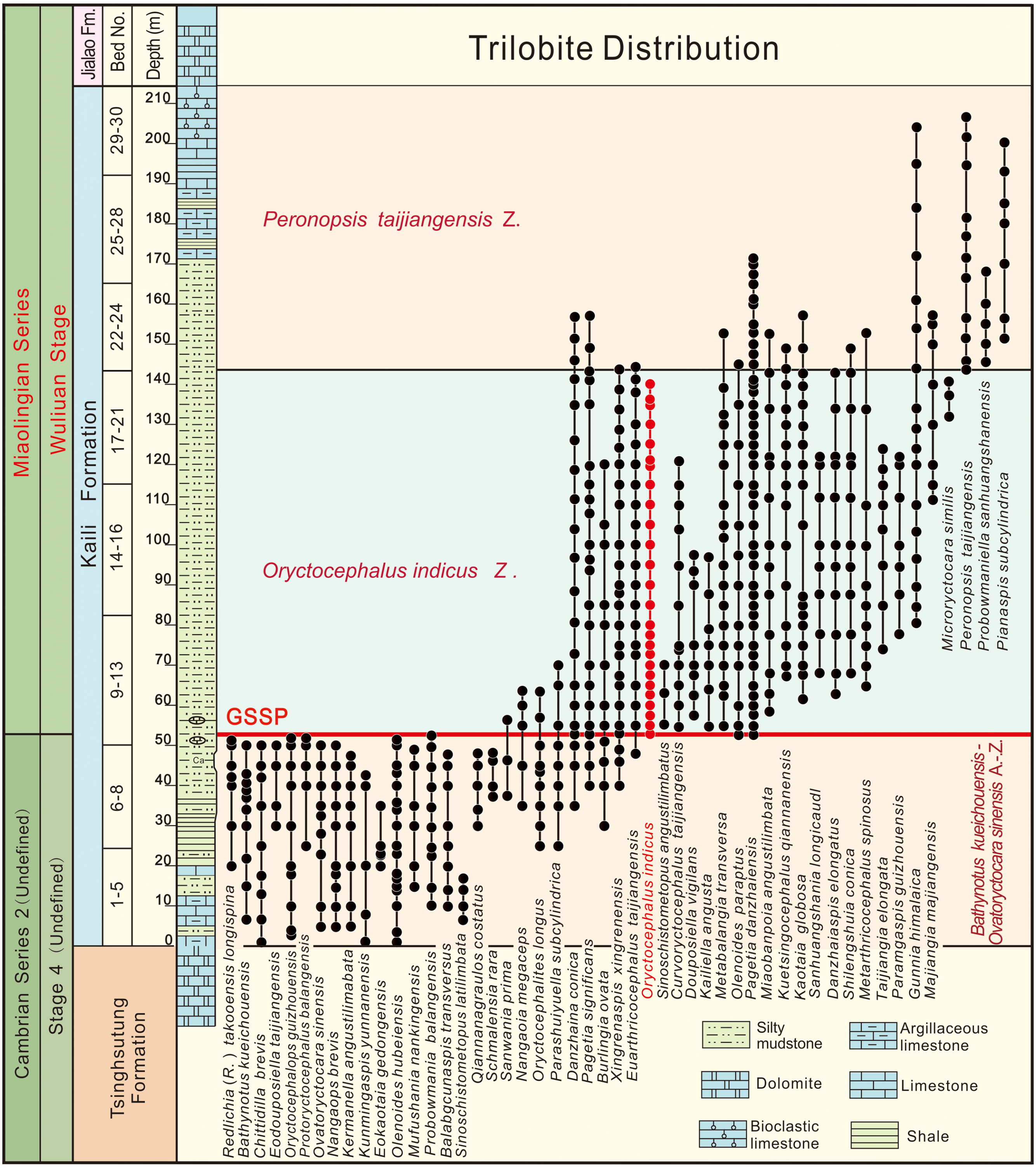

Figure 5. Observed stratigraphic distribution of trilobites in the Wuliu-Zengjiayan section near Balang, Jianhe, Guizhou, South China. The GSSP coincides with the base of the **Oryctocephalus indicus** *Zone in this section, lying 52.8 m above the base of the Kaili Formation.*

ous deposition of a succession of shales and subordinate lime mudstones across the GSSP boundary interval (Zhang et al., 1996; Yuan et al., 2002; Zhao et al., 2005, 2007, 2012a, c; Sundberg et al., 2010, 2011; Gaines et al., 2011). The section lacks generally syndepositional and tectonic disturbance at the GSSP boundary interval, although small scale folding or minor bedding-plane slippage occurs along some beds and more or less tectonic shearing happened to fossil specimens, which are expected in an inclined succession of fine-clastic strata. Bedding-plane slip surfaces do not appear to have resulted in any loss or repetition of stratigraphic thickness, and event-driven deposition was maintained across the Kaili Formation with no evidence for condensation (Gaines et al., 2011). In addition, the biostratigraphic succession in the section is consistent with numerous reference sections in the region (Zhao et al., 2001a, b, 2007; Fig. 5). Although the section has been affected by mild oxidative weathering, no evidence of significant diagenetic alteration or metamorphism is present.

Thickness and Stratigraphic Extent

The Kaili Formation is 214.2 m thick at the Wuliu-Zengjiayan section (Zhao et al., 2001a, b, 2007, 2012a, c; Yuan et al., 2002). Lithologically, the formation is subdivided into three units: the lower part is composed of thin-bedded limestones with silty mudstone interbeds, with a thickness of 23.7 m (Bed 1–5); the middle part, including the *Oryctocephalus indicus* Zone and the well-known Kaili Biota-bearing interval (Zhao et al., 2005, 2011), is 150.43 m thick (Bed 6–27) and is dominated by silty mudstones, mudstone, calcareous mudstone, and shale layers, containing carbonate lenticles in the lower portion; the upper part, including most of the *Peronopsis taijiangensis* Zone, consists of thin-bedded limestone layers and intercalated shale, grading into grainy limestone and bioclastic limestone with a thickness of 40.07 m (Bed 28–30; Fig. 5).

The GSSP for the base of the Miaolingian Series and the Wuliuan Stage occurs in a succession composed of greenish-grey, internally laminated silty mudstone in the mid-lower part of the Kaili Formation (Figs. 4(b)–(d), 5). The strata below the GSSP belong to the upper part of undefined Cambrian Stage 4 or to the Duyunian Stage in the terminology used for South China.

Provisions for Conservation, Protection, and Accessibility

The exposure containing the GSSP in the Balang area has received permanent protection, due to the geological significance, from the government of Guizhou since 2002, when the Balang area was approved as Jianhe Natural Reserve of Paleontological Fossils. In 2009, this area was included as a part of the Miaoling National Geopark and since then has been managed and protected by both governments of Guizhou Province and Jianhe County.

Access to the outcrop is essentially unrestricted in all seasons. Travel to Guizhou is open to persons of all nationalities, and travel for scientific purposes is always welcomed. Ordinary vehicles can be driven from the Jianhe Township directly to Balang or Tunzhou village in no more than 20 minutes. From either village, the GSSP is easily reached by 20–30 minute walking via paved paths.

Motivation for Selection of the Boundary Level and of the Potential Stratotype Section

Principal Correlation Event (marker) at GSSP Level

The oryctocephalid trilobite *Oryctocephalus indicus* (Reed, 1910) (Fig. 6(a)–(d)) has an intercontinental distribution and its first appearance has been acknowledged as one of the most favorable level for the GSSP defining the base of a global stage (e.g. Jell and Hughes, 1997; Yuan et al., 1997; Hughes and Jell, 1999; Sundberg et al., 1999, 2010, 2011, 2016; Geyer and Shergold, 2000; Korovnikov, 2001, 2006; Peng and Babcock, 2001; Shergold and Geyer, 2001, 2003; Zhao et al., 2001a, b, 2004, 2006, 2007, 2012a, b, c, 2014, 2017; Yuan et al., 2002; Peng, 2003; Sundberg and McCollum, 2003; Babcock et al., 2005, 2014; McCollum and Sundberg, 2005, 2007; Peng et al., 2006, 2012b; Geyer and Peel, 2011; Hughes, 2016; Singh et al., 2016; Esteve et al., 2017; Zhao et al., 2017). Besides South China, the species has been identified from northern India (Indian Himalaya) (Reed, 1910; Jell and Hughes, 1997; Peng et al., 2009b; Hughes, 2016; Singh et al., 2016), western USA (Sundberg and McCollum, 1997, 2003), North Greenland (Geyer and Peel, 2011), North Korea (Saito, 1934), and more possibly from Siberia (Korovnikov, 2001, 2006; Zhao et al., 2006; Fletcher, 2007; Shabanov et al., 2008; Hughes, 2016; Esteve et al., 2017).

Oryctocephalus indicus provides the best and most precise tool for intercontinental correlation in the lower part of Cambrian Series 3 (Zhao et al., 2001a, b, 2012a, b, c, 2014; Yuan et al., 2002; Sundberg et al., 2010, 2011, 2016; Geyer and Peel, 2011; Yuan and Ng, 2014; Hughes, 2016). Some widely distributed trilobites in the *O. indicus* Zone also provide fine tools for intercontinental correlation.

The primitive form of *Oryctocephalus indicus* makes its first appearance in the lower–middle part of the Kaili Formation in the Balang-Chuandong area, Jianhe County, Guizhou Province. Specimens of *O. indicus* with the primitive morphology possess only two pairs of marginal spines on the pygidium. These forms are succeeded and replaced by the advanced morphotype, characterized by three pairs of pygidial marginal spines (Yuan et al., 2002). The advanced form of *O. indicus* occurs in the *O. indicus* Zone of Nevada and California, USA (Sundberg and McCollum, 1997, p. 1075), and the interval of its occurrence can be correlated with the middle–upper part of the *O. indicus* Zone of South China. *Oryictocephalus americanus* from the *Amecephalus arrojosensis* Zone in Nevada, USA (Sundberg and McCollum, 2003), also shows the primitive feature of *O. indicus.* Specimens assigned to *O. americanus* lack connected transglabellar furrows (S2, S3), apparently as a result of taphonomic bias. Sundberg (personal communication, 2008) suggested that it gave rise to the advanced form of *O. indicus* but Zhao et al. (2006, 2007) and Esteve et al. (2017) preferred to regard it as a junior synonym of *O. indicus.* The FAD of *O. indicus* always succeeds the disappearance of *Olenellus* in Laurentia and *Redlichia* in the Indo-Pacific faunal province, allowing precise correlation among these levels in different faunal realms.

Stratigraphically, the first appearance of the primitive form of *Oryctocephalus indicus* at the Wuliu-Zengjiayan section lies 1.2 m above the LAD of the redlichiid trilobite *Bathynotus* and 0.2 m above the LAD of *Redlichia* (Sundberg et al., 2011). In the western United States, the first appearance of *O. indicus* (=*O. americanus*) succeeds

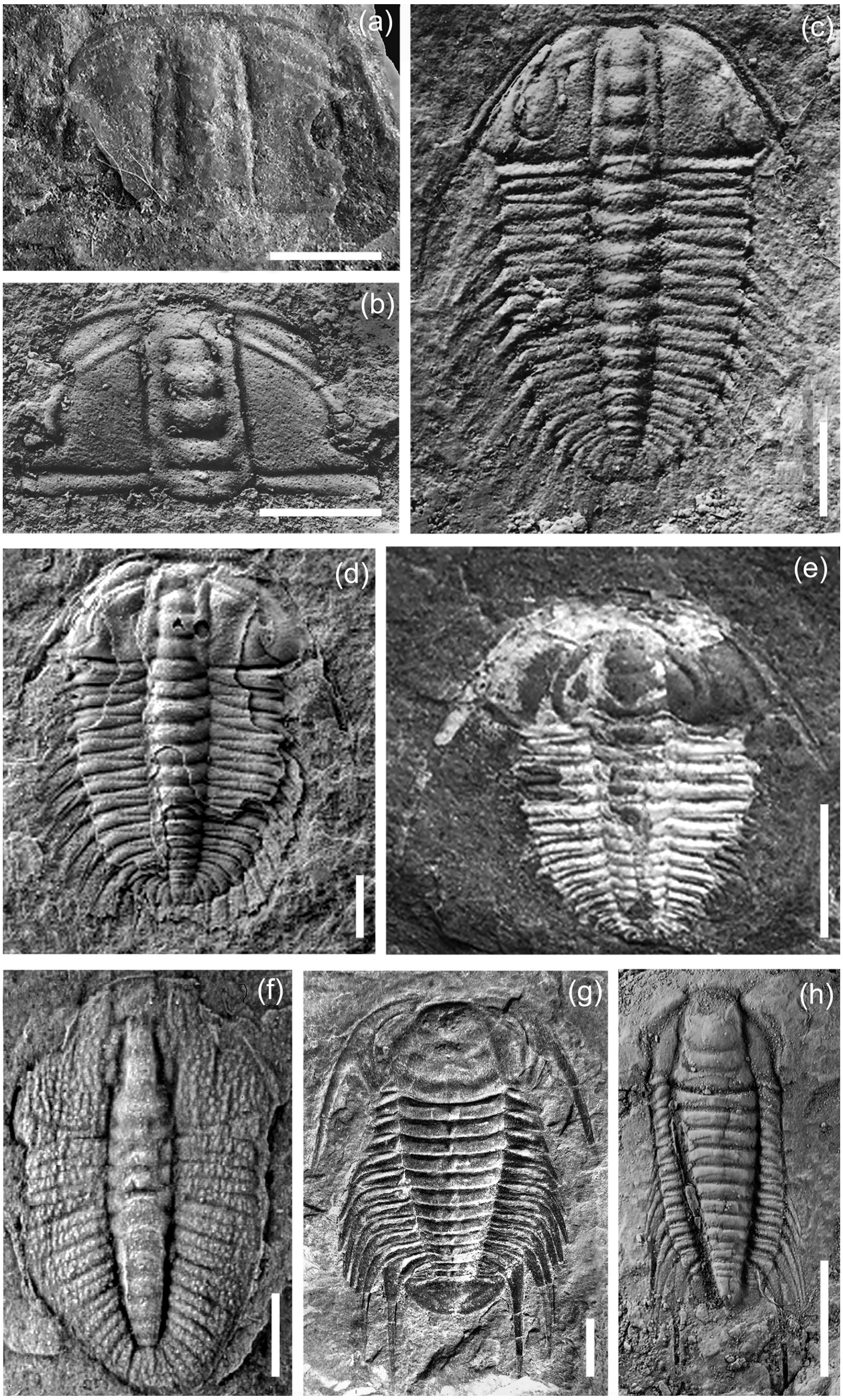

Figure 6. Key trilobite species used for recognition of the base of the Miaolingian Series and Wuliuan Stage. All specimens were collected from the Kaili Formation of the Wuliu-Zengjiayan section; all are dorsal views, collecting horizons are in meters above the base of the formation, (a)–(d) **Oryctocephalus indicus** *(Reed, 1910). (a) cranidium, GTBB1-15-19a, 52.8 m (first appearance datum); (b) Cranidium, GTB17-5-119, 120.80 m; (c) Exoskeleton, GTB 20-5-1554, 135.70 m; (d) Exoskeleton, GTB 11-111, 56.70 m; (e)* **Redlichia (R.) takooensis longispina** *Guo and Zhao, 1998, exoskeleton, GTBB1-3-3, 49.4 m; (f)* **Ovatoryctocara sinensis** *Zhao, Yuan, Peng, Yang et Esteve, 2015, exoskeleton, GTBFZK-42, 51.8 m; (g)–(h),* **Bathynotus kuichouensis** *Lu in Wang et al., 1964. (g) Exoskeleton, GTB6-3-25, 25.9 m; (h) Exoskeleton, GTBB1-47-1, 40.6 m. Scale bars = 1 mm for figs. (a)–(b), 2 mm for figs. (c)–(f), 5 mm for figs. (g)–(h).*

the disappearance of *Olenellus*. The combination of the FAD of *O. indicus*, the narrow stratigraphic range of *O. indicus,* the stratigraphically abrupt disappearance of redlichiids and olenellid trilobites, and evolutionary advances in oryctocephalids and ptychopariids allows the base of the Wuliuan Stage to be tightly constrained. *Bathynotus*, which occurs at the top of Cambrian Stage 4, is a guide fossil found in the western United States, Siberia, Australia and South China (Webster, 2009; Peng et al., 2014). Its distribution overlaps that of *Olenellus* and *Redlichia*, and this taxon has been treated as the most effective secondary tool for intercontinental correlation.

As discussed previously (Babcock et al., 2004, 2007; Peng et al., 2004b, 2006), the selection of a GSSP in open-shelf to slope deposits, and particularly in one from a low-latitude region such as the South China Platform, is desirable. Slope settings of the Cambrian favored a combination of cosmopolitan trilobites including agnostoids, oryctocephalids and polymerids, such as *Pagetia significans, Euarthricocephalus* and *Curvoryctocephalus* in the *Oryctocephalus indicus* Zone, *Bathynotus*, *Ovatoryctocara* and *Redlichia* in the *Bathynotus kueichouensis–Ovatoryctocara sinensis* Assemblage-Zone, and *Olenoides* and *Burlingia* in that zone and the *Oryctocephalus indicus* Zone as well. This combination of taxa enables a precise stratigraphic correlation into the Siberia, Greenland, and Laurentia (Geyer and Peel, 2011; Sundberg et al., 2016). In addition, based on the important trilobite taxa *Acadoparadoxides*, *Eccaparadoxides* and *Micmacca*, the base of the Wuliuan Stage can be correlated across the Mediterranean region (e.g., Morocco, Turkey and Spain) and also to Siberia and Australia (Liñán et al., 2004, 2008; Gozalo et al., 2007, 2011a, b; Geyer, 2016) although direct correlation of Mediterranean successions to other continents is difficult (Álvaro et al., 2003, 2013; Gozolo et al., 2007; Sundberg et al., 2010, 2016; Geyer and Peel, 2011; Zhao et al., 2012a). However, with the aid of Siberian taxa, the base of the Wuliuan Stage can be correlated, more or less confidently, with that of the Mediterranean region.

Stratotype Section and Point

The stratotype Wuliu-Zengjiayan section consists mainly of the Kaili Formation that rests conformably on the Tsinghsutung Formation and is overlain conformably by the Jialao Formation (Figs. 4(a), 5, 7, 9). Both the Tsinghsutung and Jialao formations are of dolomite facies.

The Kaili Formation in the Wuliu-Zengjiayan section is a mostly monofacial succession of silty mudstone, mudstone, calcareous mudstone and shale with subordinate gray limestone-marlstone in the basal part and limestone in the uppermost parts of the formation (Zhao et al., 2001a, b; Gaines et al., 2011). Soft-sediment deformation, truncation surfaces, and slide surfaces are rare in the section and absent near the GSSP, suggesting deposition on a gentle slope. The interval of the FAD of *O. indicus* is inferred to be a maximum flooding stage of the major eustatic transgression (Zhu et al., 1999; Gaines et al., 2011; Fig. 7).

The Kaili Formation embraces three trilobite zones, including two polymerid zones and one agnostoid zone (Zhao et al., 2012a, c, 2015, 2017; Fig. 5), in ascending order: the *Bathynotus kueichouensis-Ovatoryctocra sinensis* Assemblage-Zone (4.0–52.8 m above the base of the Kaili Formation), the *Oryctcocephalus indicus* Zone (52.8–143.78 m above the base of the Kaili Formation), and the *Peronopsis taijiangensis* Zone (143.78–214.2 m above the base of the Kaili Formation). As mentioned above, the trilobite zonal succession of the Kaili Formation in the Wuliu-Zengjiayan section reveals a complete, tectonically undisturbed, marine succession.

Oryctocephalus indicus makes its first appearance at 52.8 m above the base of the Kaili Formation (Fig. 6(a)), a level defining the base of the Miaolingian Series and Wuliuan Stage (Zhao et al., 2001a, b, 2006, 2007, 2008, 2012a, 2014; Sundberg et al., 2010, 2011). This point in the Wuliu-Zengjiayan section demonstrates a major change in faunal assemblages with the extinction of redlichiids and *Bathynotus* and the appearance of several new ptychoparid taxa, although some oryctocephalid taxa exhibit ranges that cross this horizon (Fig. 5). Current stratigraphic resolution suggests that the FAD of *O. indicus* in

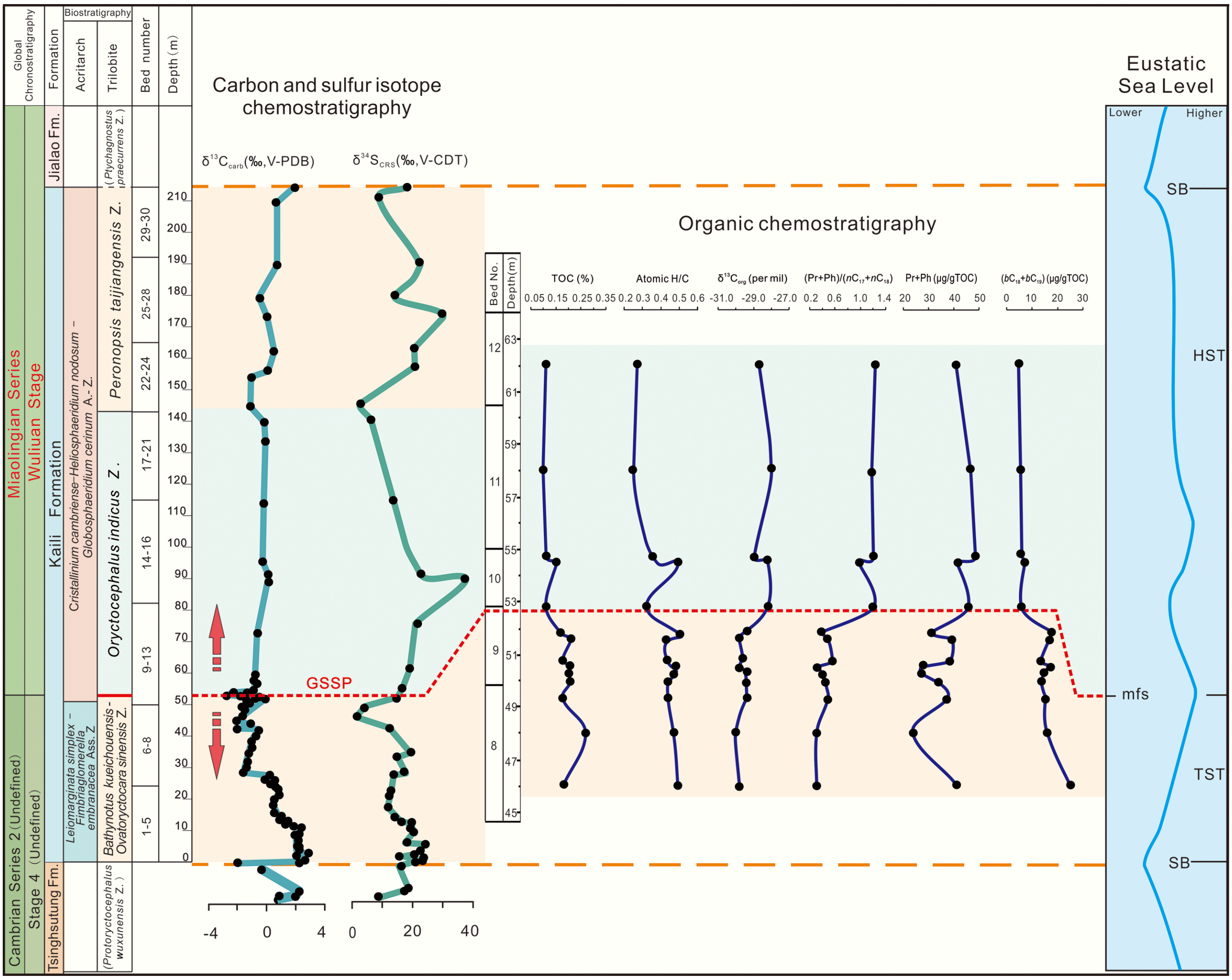

Figure 7. Summary of primary and secondary stratigraphic indicators for the base of the Miaolingian Series and Wuliuan Stage of the Cambrian System. Major stratigraphic tools used to constrain the GSSP of the series and stage are trilobite biostratigraphy (Zhao et al., 2007, 2012, 2015), acritarch biostratigraphy (Yin et al., 2010), carbon and sulfur isotope chemostratigraphy (Guo et al., 2010a, b, 2014), organic chemostratigraphy (Wang et al., 2014) and sequence stratigraphy (Gains et al., 2011). Abbreviations: TOC = total organic carbon content in rocks; atomic H/C = atomic hydrogen/carbon ratio; $d^{13}C_{org}$ data were measured on kerogen samples; Pr = pristane; Ph = phytane; nC_{17}, = normal C_{17}; nC_{18} = normal C_{18}; bC_{18} and bC_{19} = C_{18} and C_{19} midchain monomethyl branched alkanes, respectively, based on m/z 126+140+154+168+196+210+224 mass chromatograms; mfs = maximum flooding surface; SB = sequence boundary; HST = Highstand Systems Tract; TST = Transgressive Systems Tract.

the major Cambrian realms is equivalent in age. In the Wuliu-Zengjiayan section, *O. indicus* ranges across a 90.98 m interval, which is well fossiliferous, especially in its lower portion. The high-resolution data on distributions of trilobite taxa through the stratigraphic interval containing the GSSP in the Wuliu-Zengjiayan section are summarized in Fig. 5. In addition to *O. indicus*, a number of other guide fossils, which have utility for correlation on either an intercontinental or an interregional scale, help to constrain the position of the boundary. The major faunal changes below and above the FAD of *O. indicus* provide excellent data for global correlation of the boundary interval of the Wuliuan Stage. Among the key trilobite levels in the boundary interval, the LADs of *Ovatoryctocara sinensis* (48.8 m above the base of the Kaili Formation, Figs. 5, 6(f)) and *Bathynotus kueichouensis* (48.8 m above the base of the Kaili Formation, Figs. 5, 6(g–h)) can serve as secondary biostratigraphic correlation tools for identifying, with more or less precision, the base of the Miaolingian Series and the Wuliuan Stage (Zhao et al., 2001a, b, 2007, 2012c, 2014; Geyer, 2005; Fletcher, 2007; Peng et al., 2009; Sundberg et al., 2011).

The Wuliu-Zengjiayan section bears exceptionally preserved Burgess-type biota, termed the Kaili Biota. The biota occurs slightly above the FAD of *Oryctocephalus indicus*, containing representatives of at least 11 phyla that include algae, sponges, chancelloriids, cnidarians, “worms”, lobopodia, medusiform fossils, brachiopods, molluscs, arthropods, echinoderms and various problematic fossils, of which some of the taxa are non-biomineralizing (Zhao et al., 2005, 2011; Fig. 8). This important biota can serve to constrain the position of the base of the Miaolingian Series and Wuliuan Stage at least in South China.

Besides trilobites and the exceptionally preserved taxa of the Kaili

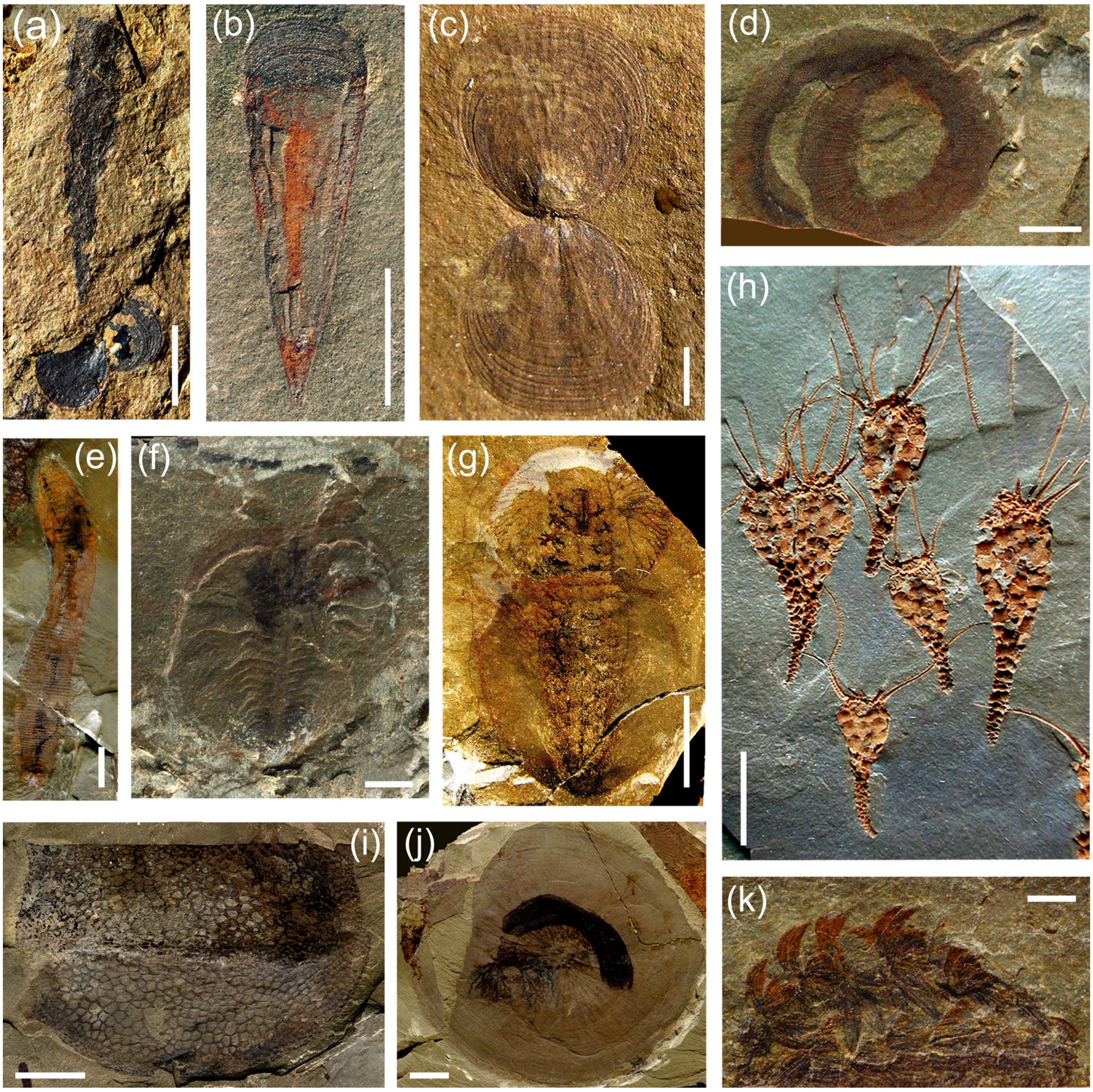

Figure 8. Some metazoan taxa from the exceptionally preserved Kaili Biota in Balang Area, Jianhe, Guizhou. (a) **Angulosuspongia sinensis** ***Yang, Babcock et Peng, 2017 attached to*** **Glyptacrothele bohemica*****, GTBM-9-2-1971; (b)*** **Haplophrentis** ***cf.*** **H. carinatus** ***Matthew, 1899, GTBM-9-3162; (c)*** **Acrothele** ***sp., GTBM-9-5365; (d) Palaeoscolecid, gen. et sp. indet., GTBM-9-1b; (e)*** **Ottoia guizhouensis** ***Yang, Zhao et Zhang, 2016, GTBM-9-4166; (f) Marrella sp., ventral view, GTBM-9-5-1075; (g)*** **Naraoia** ***cf.*** **N. compacta** ***Walcott, 1912, showing thin vessels in cephalic area, GTBM-9-3-5098; (h)*** **Sinoeocrinus lui** ***Zhao, Huang et Gong, 1994, GTB-9-5-3495; (i) Tuzoia bispinosa Yuan et Zhao, 1999, GM 9-5-1248; (j)*** **Pararotadiscus guizhouensis** ***Zhao and Zhu, 1994, GTBJ-13-3-220; (k)*** **Wiwaxia taijiangensis** ***Zhao, Qian et Li., 1994, with articulated specimen, GTBM-9-5-8888a. Scale bars equal 5 mm for (a), (b), (e), (g), (i); 10 mm for (h), (j) and 2 mm for others.***

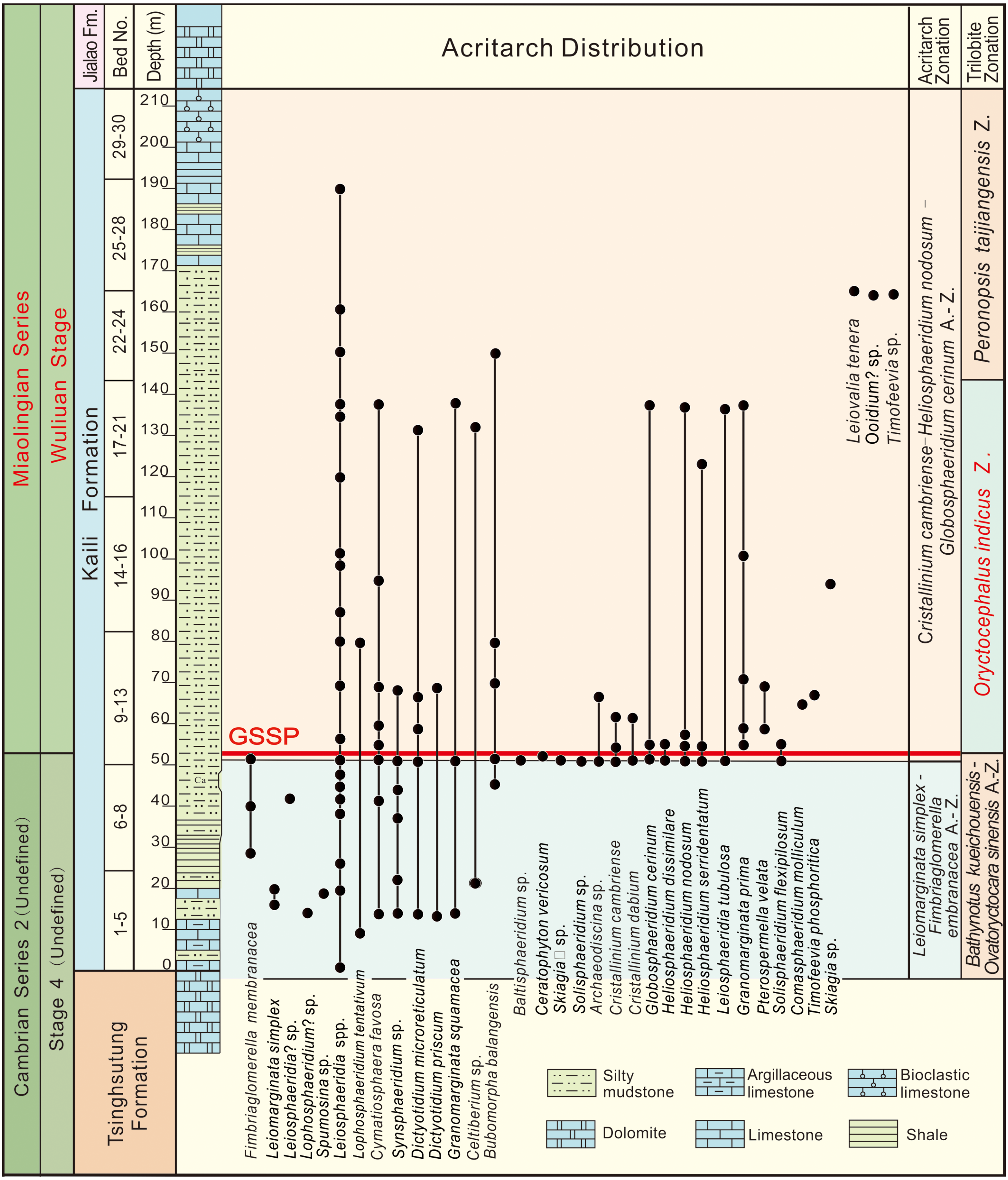

Figure 9. Observed stratigraphic distribution of acritarchs in the Kaili Formation of the Wuliu-Zengjiayan GSSP section (modified from Yin et al., 2010).

Biota, the acritarch assemblage from the Wuliu-Zengjiayan section shows a prominent change close to the FAD of *Oryctocephalus indicus* (Yin and Yang, 1999; Yang and Yin, 2001; Yin et al., 2009, 2010; Figs. 9, 10). The *Leiomarginata simplex-Fimbriaglomerella membranacea* assemblage (0–52 m above the base of the Kaili Formation) below the datum is clearly replaced by the *Cristallinium cambriense-Heliosphaeridium nodosum-Globosphaeridium cerinum* assemblage (52–140 m above the base of the Kaili Formation). This turnover in microfossil assemblages closely corresponds with the major change in trilobite assemblages (Yin and Yang, 1999; Yin et al., 2009). This result has been confirmed by detailed, bed-by-bed sampling for palynomorphs across a 4 m interval bearing the FAD of *O. indicus* (50.8–54.8 m in Wuliu quarry, Fig. 4(b), (d)) (see Yin et al., 2010). Thus, the acritarch assemblages also help to constrain the base of the Miaolingian Series and Wuliuan Stage, and provide another fossil tool for correlating the boundary interval of South China to those of Baltica and Gondwana, in which the acritarch biostratigraphy has been reported in details (Volkova, 1990; Moczydłowska, 1998, 1999; Palacios, 2015; Moczydłowska and Yin, 2012).

Regional and Global Correlation

The FAD of *Oryctocephalus indicus* in the stratotype Wuliu-Zengjiayan section is one of the most easily recognizable horizons in the Cambrian (see Geyer and Shergold, 2000; Fig. 2). In South China, it is used for defining the base of the regional Wulingian Series and Taijiangian Stage (Peng et al., 2000; Peng and Babcock, 2001). Possible suitability of the FAD of this species for marking a global stage and series boundary has been summarized principally by Shergold and Geyer (2003), and Peng et al. (2004a, b, 2006). Key correlation tools are biostratigraphic ranges of polymerid trilobites, agnostoid trilobites, acritarchs; carbon isotopic ratios; sulfur isotopic ratios; and organic chemostratigraphy; and sequence stratigraphy.

Polymerid Trilobite Biostratigraphy

Two polymerid biozones are recognized in the lower-middle part of the Wuliu-Zengjiayan section (Zhao et al., 2001a, b, 2012a, c, 2015, 2017; Yuan et al., 2002), the lower *Bathynotus kueichouensis-Ovatoryctocara sinensis* Assemblage-Zone and the overlying *Oryctocephalus indicus* Zone (the lowermost zone of the Wuliuan Stage) with their boundary defined by the FAD of *O. indicus* (Figs. 4(a), 5). These two zones have been recognized in a number of sections of the Kaili Formation in eastern Guizhou, for example, the Miaobanpo (Zhao et al., 2001a, b, 2005, 2011), the Jianshan (Zhao et al., 2008), the Fujiachong (Zhao et al., 2012a), the Sanwan (Zhao et al., 2012b) and the Pingzhai (Yuan et al., 2002; Zhao et al., 2012a) sections. The level coinciding with FAD of *O. indicus* may correlate to the base of the Tianpeng Formation of platform facies in Mengzi County of Yunnan Province, South China (Zhao et al., 2014), the base of *Amecephalus arrojosensis* Zone of Emigrant Formation in Great Basin, USA, and occurs in the Parahio Formation, Spiti area, Indian Himalaya (see Singh et al., 2016; Hughes et al., 2018), and the corresponding level in northwestern Korea (Saito, 1934).

Although most of the polymerid trilobites from the biozones are endemic, a few of them provide, more or less, correlation tools of regional or intercontinental scale and allow tielines to be established into some other Cambrian faunal realms. Particularly useful guide fossils are the pandemic forms such as *Oryctocephalus indicus*, *Ovatoryctocara*, *Oryctocephalops*, *Oryctocephalites*, and *Burlingia* (Reed, 1910; Saito, 1934; Lermontova, 1940; Shergold, 1969; Lu et al., 1974; Zhang et al., 1980; Whittington, 1994; Jell and Hughes, 1997; Sundberg and McCollum, 1997, 2003; Yuan et al., 1997, 2002; Zhao et al., 2001a, b, 2006, 2012b, 2014; Sundberg et al., 2011, 2016; Geyer and Peel, 2011; Yuan and Esteve, 2015; Hughes, 2016; Singh et al., 2016; Esteve et al., 2017), the nektobenthic forms such as *Redlichia* and *Bathynotus* (Kobayashi, 1935; Lu, 1950; Lu and Chien, 1964; Öpik, 1970; Zhang et al., 1980; Whittington, 1988; Guo et al., 1999; Shergold and Whittington, 2000; Yuan et al., 2002; Kruse et al., 2004; Peng et al., 2009, 2014; Webster, 2009; Goryaeva et al., 2012; Hughes, 2016; Laurie, 2016), and the benthic trilobite *Olenoides* that has an intercontinental distribution (Yuan et al., 1997, 2002; Wang et al., 2016).

Agnostoid Trilobite Biostratigraphy

A single agnostoid biozone, the *Peronopsis taijiangensis* Zone, is recognized in the upper part of the Wuliu-Zengjiayan section (Yao et al., 2009), replacing the previous *Oryctocephalus orientalis* Zone of Yuan et al. (2002). It lies immediately above the *Oryctocephalus indicus* Zone (Fig. 5), and in eastern Guizhou and western Hunan it is overlain by the agnostoid *Ptychagnostus gibbus* Zone of the Huaqiao Formation (Peng, 2009, 2018). The *Peronopsis taijiangensis* Zone is correlatable with the *Ptychagnotus praecurrens* Zone of Laurentia, where the agnostoid *Ptychagnotus praecurrens* Zone, together with the overlying *Ptychagnotus gibbus* Zone, correlates with the upper half of the polymerid *Oryctocephalus* Zone (Robison and Babcock, 2011; Babcock et al., 2017). *Ptychagnotus praecurrens* is a widespread agnostoid trilobite, known from Sweden (Westergård, 1946; Weidner and Ebbestad, 2014; Ahlberg et al., 2019), England (Rushton, 1966), Russia (Siberia) (Egorova et al., 1976; Naimark, 2008; Shabanov et al.,2008), Australia (Laurie, 2004; Kruse et al., 2009), the USA (Utah and Nevada) (Robison, 1982; McCollum and Sundberg, 2007, Sundberg, 2011), and probably from Kazakhstan (Ergaliev and Ergaliev, 2008).

Although *Ptychagnotus praecurrens* has not been recorded in South China (likely due to facies restriction), strata corresponding to the *P. praecurrens* Zone are apparently present, i.e. the Aoxi Formation in northwestern Hunan, which is composed of grey to light grey, thin- to thick-bedded dolomites but straigraphically is overlain by the *P. gibbus*-bearing Huaqiao Formation (Peng and Robison, 2000). In the Wuliu-Zengjiayan section, the eodiscid trilobite *Pagetia significans* makes its first appearance slightly below the FAD of *O. indicus* (Sundberg et al., 2016; Fig. 5). *Pagetia significans* has been recorded from the Miaolingian strata of Australia (Jell, 1975), North Korea (Kobayashi, 1944), and Indian Himalaya (Jell and Hughes, 1997; Singh et al., 2016).

Acritarch Biostratigraphy

As phytoplanktic microfossils, Cambrian acritarchs are of significance to assist in delineating faunal zones, for indicating changes in the depositional environment, and even defining geological or biological events.

The taxonomic change in organic-walled microfossils (acritarchs) in the Wuliu-Zengjiayan section has been intensively studied (Yin et al., 2010). As discussed above, two acritarch assemblages, the *Leiomarginata simplex-Fimbriaglomerella membranacea* assemblage and the *Cristallinium cambriense-Heliosphaeridium nodosum-Globosphaeridium cerinum* assemblage are recognized below and above the GSSP respectively (Fig. 9). These acritarch assemblage zones are based on continuous sampling of the whole section, and more intensive sampling across a 4 m interval (50.8–54.8 m above the base of the Kaili Formation). Many acanthomorphic acritarch forms, such as *Helios-*

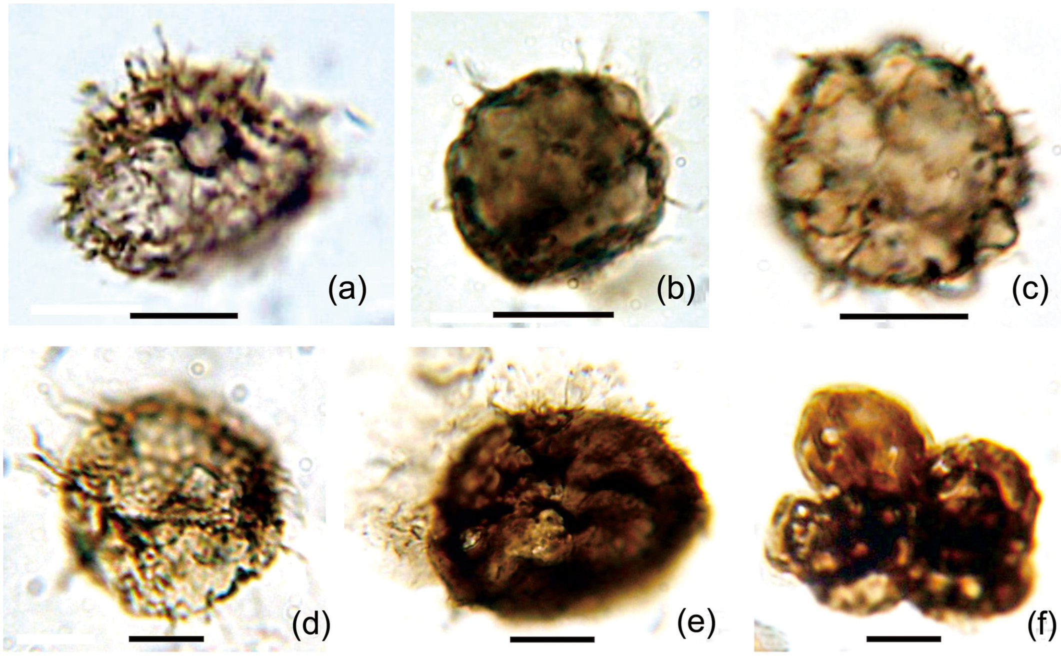

Figure 10. Acritarchs from the Kaili Formation of the Wuliu-Zengjiayan section. Sample numbers are prefixed with either FZX or K. (a)* Heliosphaeridium nodosum *Moczydłowska, 1998, FZX25; (b), (c)* Globosphaeridium cerinum *(Volkova) comb. Moczydłowska, 1991, FZX-25b, FZX24c; (d)* Solisphaeridium flexipilosum *(Slavicova) comb. Moczydłowska, 1998, FZX26; (e)* Comasphaeridium molliculum *Moczydłowska and Vidal, 1988, K69; (f)* Synsphaeridium *sp., K51. All scale bars equal 10 µm.

phaeridium dissimilare, H. nodosum, H. serridentatum, Globosphaeridium cerinum, and *Solisphaeridium flexipilosum* (Fig. 10), exhibit a first appearance at 52.3–52.7 m above the base of the Kaili Formation), which is slightly below the GSSP for the base of Miaolingian Series and Wuliuan Stage.

Heliosphaeridium nodosum, H. dissimilare, H. serridentatum, Globosphaeridium cerinum, *Solisphaeridium frixipilosum* also mark the base of the traditional middle Cambrian in Baltica, and Gondwana (Volkova, 1990; Moczydłowska,1998, 1999; Moczydłowska and Yin, 2012; Palacios, 2015). On the basis of the present record and existing data, it is noted that many species referred to *Heliosphaeridium* range from the provisional Cambrian Series 2 through the Miaolingian Series are even restricted to the Miaolingian Series. Therefore, certain species of *Heliosphaeeridium*, such as *H. dissimilare* and *H. serridentatum*, appear to characterize the Miaolingian Series.

More recently, acritarch assemblages and cryptospore-like microfossils have been obtained from stratigraphic successions spanning the *Oryctocephalus indicus* Zone in the Parahio Valley (Spiti), Indian Himalaya, and the Log Cabin Mine section, eastern Nevada, USA (Yin et al., 2013), showing the obvious change in acritarch taxonomy near the FAD of *Oryctocephalus indicus*. Such a change is significant and indicates an important geobiological event (Yin et al., 2016).

Carbon Isotope Chemostratigraphy

The carbon isotopic composition of carbonate rocks varies between –2.7 and +3.1‰ in the Wuliu-Zengjiayan section (Yang et al., 2003; Guo et al., 2005, 2010a, b). There is a stepwise decline from the base of the Kaili Formation towards the GSSP level, which is marked by peak negative values. Subsequently, there is a long relative stable interval with average seawater values between 0 and 1, and then the formation top (last sample) has a minor positive excursion. The base of the *Oryctocephalus indicus* Zone is marked by a distinctive peak of a rather long negative $\delta^{13}C_{carb}$ excursion with minimum values of –2.7‰ (Fig. 7). Thus, a distinct negative excursion in the carbon isotopic composition occurs from the *Bathynotus kueichouensis–Ovatoryctocara sinensis* Assemblage-Zone through the *O. indicus* Zone. This excursion, near the conterminous base of the Miaolingian Series and Wuliuan Stage, can also be recognized at the Jianshan section nearby (Guo et al., 2010a, b), at other localities on the Yangtze Platform, South China (Zhu et al., 2004), in Siberia (Shabanov et al., 2008), and North America (Montañez et al., 2000; Dilliard et al., 2007).

Sulfur Isotope Chemostratigraphy

The sulfur isotopic composition of sedimentary pyrite displays a similar variation across the provisional Cambrian Series 2 through the Miaolingian Series in the Wuliu-Zengjiayan section (Guo et al., 2014). A shift from $\delta^{34}S_{CRS}$ values around 1.3‰ to more positive values of 19.8‰ through the lower part of Kaili Formation. An excursion towards less ^{34}S enriched values is located slightly below the level of the Cambrian Series 2 to Cambrian Series 3 transition. There are two separate positive excursions in the middle and upper Kaili Formation, and an additional third one occurs at the formation top. The evolution towards more positive $\delta^{34}S$ values could reflect the development of closed system conditions in the early burial environment with respect to sulfate availability in the pore water realm. Comparably ^{34}S enriched pyrite sulfur isotope values and a somewhat similar variation across this stratigraphic transition have been observed in other sections of northwest Spain (Wotte et al., 2012), southern France (Wotte et al., 2012), the

Siberian Platform (Wotte et al., 2011), the USA (Wotte et al., 2011), and Mexico (Loyd et al., 2012).

Organic Chemostratigraphy

Organic geochemical investigations for the boundary interval of the Wuliu-Zengjiayan GSSP section (Bed 8–12) shows that all the geochemical proxies, such as TOC content, $\delta^{13}C_{org}$, atomic H/C value of kerogen, as well as biomarker parameters, co-vary across the section and change rather sharply across the boundary between the provisional Cambrian Series 2 and the Miaolingian Series at the top of Bed 9 (Wang et al., 2014; Fig. 7). For example, the relative abundance of isoprenoid hydrocarbons to *n*-alkanes (or the absolute concentration to TOC) shows an upward increase across the boundary with the $(Pr+Ph)/(nC_{17}+nC_{18})$ values ranging in 0.31–0.56 in the provisional Stage 4 sediments, as compared to 0.98–1.24 in the Wuliuan Stage. The $\delta^{13}C_{org}$ trend is also in accord with the abrupt change in $\delta^{13}C_{carb}$ across the boundary (Guo et al., 2010a, b; Fig. 7).

In general, changes observed are interpreted to reflect primary depositional values, notably variations in the composition of primary productivity and the marine redox condition (Wang et al., 2014). These, in turn, are linked to biological changes (i.e. trilobites and acritarchs respectively; Figs. 5, 6, 9, 10) and a possible regional and global anoxia–extinction event across the transition from the Series 2 to the Miaolingian Series. The extinction of multiple trilobite species at the end of Series 2 is probably related to global anoxia as evidenced by carbon and sulfur isotopes (Guo et al., 2010a, b, 2014; Fig. 7) and organic geochemical result (Wang et al., 2014). Evidently, the organic chemostratigraphic evidences also strongly support to place the base of the Miaolingian Series and Wuliuan Stage at this level.

Sequence Stratigraphy

Sea level changes corresponding to 3rd and 4th order depositional cycles (Fig. 7) caused migration of the adjacent Yangtze carbonate platform, the proximity of which controlled the amount of carbonate sediment delivered to the open-shelf to slope settings upon which the Kaili Formation was deposited. Initial Kaili deposition represents the onset of flooding on the slope. The lower portion of the Kaili Formation has been interpreted to represent a transgressive interval, with maximum flooding in the interval surrounding the GSSP at 52.8 m above the base of the formation (Gaines et al., 2011). The remaining thickness of the middle and upper Kaili Formation is interpreted as a highstand system tract with gradual shallowing and accompanying seaward progradation of the Yangtze carbonate platform, manifested an overall increase in the presence of thin, interbedded carbonates upsection toward the contact with the overlying mixed-siliciclastic carbonate Jialao Formation. The Kaili-Jialao succession has been interpreted to be a complete 3rd order depositional cycle, representing transgression, maximum flooding, and a protracted period of regression accompanied by basin filling (Wang et al., 2006).

Other Regional Reference Sections

For comparative purposes, the Jianshan and Sanwan sections in eastern Guizhou have been studied in detail (Zhao et al., 2008, 2012b). Both sections bear the FAD of *Oryctocephalus indicus* and also fulfill, more or less, the biostratigraphic requirements for a GSSP. Both sections are available with unrestricted access for research purposes. The Sanwan section appears to be a good auxiliary to the Wuliu-Zengjiayan GSSP section if it could receive intensive study in future. The Jianshan section is similar to the Wuliu-Zengjiayan section in litho- and bio-stratigraphic features, but it bears a small tectonic fold within the *O. indicus* Zone (at *ca*. 78.5 m above the base of the Kaili Formation) (Zhao et al., 2008).

Best Estimate of Age for the Base of the Proposed Miaolingian Series and Wuliuan Stage

The age for the base of Miaolingian Series and Wuliuan Stage is estimated at 509.1 ± 0.22 Ma. This age is based on an ash bed in the Upper Comley Sandstone of Shropshire, United Kingdom, which has given a weighted mean $^{206}Pb/^{238}U$ age of 509.02 ± 0.79 Ma on four (of six) single grain fractions (Harvey et al., 2011). This age was newly recalibrated to 509.1 ± 0.62 (with λ errors) by the Isotope Geology Laboratory of Boise State University, USA, as one of the high-resolution radiometric ages of zircon crystals determined by TIMS for the International Commission on Stratigraphy (Peng et al., 2012b; Schmitz, 2012). From immediately overlying beds, trilobites including *Paradoxides harlani* indicate the *P. harlani* Zone of Newfoundland, which is correlatable with the *Oryctocephalus indicus* Zone of South China and Laurentia (Geyer, 2005; Fletcher, 2007), and the base of the traditional 'Middle Cambrian' (St. David's Series) in Shropshire. The base of the traditional Middle Cambrian is estimated to be 510.0 ± 1.0 Ma, an age that is constrained by U-Pb zircon ages from an ash bed in the Hanford Brook Formation, southern New Brunswick (Bowring and Erwin, 1998; Landing et al., 1998). This age was recalibrated as 508.05 ± 2.5 Ma (Peng et al., 2012b; Schmitz, 2012). Although the age of the stratigraphically older New Brunswick ash bed conflicts with the above estimated age for the base of Wuliuan Stage (509.1 ±0.62 Ma), the conflict is easily accommodated within the error ranges for the two dates. Taken together, the two dates give a well-corroborated age for the base of the Miaolingian Series and Wuliuan Stage close to 509 Ma. Montañez et al. (2000) estimated an age of ~509 Ma for the base of the traditional Middle Cambrian of Laurentia, and this estimate is close to the age provided by ICS.

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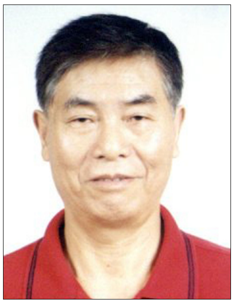

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