PROPOSED GLOBAL STANDARD STRATOTYPE-SECTION AND POINT FOR THE BASE OF THE MIAOLINGIAN SERIES AND WULIUAN STAGE （REPLACING PROVISIONAL CAMBRIAN SERIES 3 AND STAGE 5）

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CONTENTS

Introduction....................4

Proposal: Wuliu-Zengjiayan section at Balang Village, Jianhe County, in the Miaoling Mountains, eastern Guizhou Province, China as the GSSP for the base of the Miaolingian Series and Wuliuan Stage 5

1. Stratigraphic rank of the boundary....................5

2. Proposed GSSP – geography and geologic setting....................6

    2.1. Geographic location....................6

    2.2. Geological location....................6

    2.3. Location of level and specific point....................8

    2.4. Stratigraphic completeness....................8

    2.5. Thickness and stratigraphic extent....................9

    2.6. Provisions for conservation, protection, and accessibility....................10

3. Motivation for selection of the boundary level and of the potential stratotype section.................... 10

    3.1. Principal correlation event (marker) at proposed GSSP level....................10

    3.2. Potential stratotype section and point....................13

    3.3. Demonstration of regional and global correlation....................15

        3.3.1 Polymerid trilobite biostratigraphy....................15

        3.3.2 Agnostoid trilobite biostratigraphy....................16

        3.3.3 Acritarch biostratigraphy....................17

        3.3.4 Chemostratigraphy....................18

            3.3.4.1 Carbon isotope chemostratigraphy....................18

            3.3.4.2 Sulfur isotope chemostratigraphy....................18

            3.3.4.3 Organic chemostratigraphy....................19

        3.3.5 Sequence stratigraphy....................20

4. Other regional candidate sections and reasons for rejection....................20

5. Extraregional sections....................20

6. Best estimate of age for the base of the proposed Miaolingian Series and Wuliuan Stage.................... 22

7. Results of voting and comments on the proposal from the International Subcommission on Cambrian Stratigraphy 23

7.1. Ballot item and voting results, ISCS 23
7.2. Comments on the proposal from the ISCS 23
References 25
Figures with captions 41

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). It is expected that within each series two to three stages will be recognized. The stage boundaries will correspond to horizons that can be precisely correlated with confidence through all paleocontinents. To date, the Cambrian boundary positions ratified by the International Commission on Stratigraphy (ICS) are: 1, the base of Terreneuvian Series and Fortunian Stage, which is also the base of Cambrian System and Paleozoic Erathem and is marked by the FAD of the *Trichophycus pedum* in Newfoundland (Brasier et al., 1994; Landing, 1994; Gehling et al., 2001; Landing et al., 2007); 2, the base of the Drumian Stage, coinciding with FAD of the *Ptychagnostus atavus* in Utah, USA (Babcock et al., 2007); 3, the base of the Guzhangian Stage, coinciding with FAD of the *Lejopyge laevigata* in Hunan, South China (Peng et al., 2007); 4, the base of the Furongian Series and Paibian Stage, coinciding with FAD of the *Glyptagnostus reticulatus* in Hunan, South China (Peng et al., 2004a); and 5, the base Jiangshanian Stage, coinciding with FAD of the *Agnostotes orientalis* in Zhejiang, Southeast China (Peng et al., 2012a)(Fig. 1).

At least three candidate horizons have been proposed for defining the boundary between provisional Series 2 and Series 3 of the Cambrian System (also the boundary between provisional Stage 4 and Stage 5). After a long period of discussion within the ISCS' Working Group on Stage 5, the FAD of *Oryctocephalus indicus* (Reed, 1910) was selected by the Working Group and the ISCS as the primary tool for defining that boundary (ISCS' decision issued at the PDU2 Conference, Adelaide, Australia, 2016). The purpose of this proposal is to seek formal recognition for the common base of a global series and a global stage (provisionally termed Cambrian Series 3 and Stage 5 respectively), coinciding with the FAD of the widespread oryctocephalid trilobite *O. indicus*. Available information (Yuan et al., 1997, 1999; Sundberg et al., 1999; Peng, 2000, 2006; Peng and Babcock, 2001; Zhao et al., 2001a, b, 2004, 2006, 2007, 2008; Korovnikov, 2001, 2006; Peng et al., 2004a, b, 2012b; Babcock et al., 2005, 2007, 2011, 2014; McCollum and Sundberg, 2005; Fletcher, 2007), including new information presented here, indicates that the Wuliu-Zengjiayan section near Balang Village, Jianhe County, Guizhou Province, South China is an excellent candidate for the

GSSP of the series and the stage (Sundberg et al., 2011; Zhao et al., 2012c, 2014, 2015; Babcock et al., 2014; Esteve et al., 2017). The proposed GSSP for the base of the new series and stage is 52.8 m above the base of the Kaili Formation at the Wuliu-Zengjiayan section (Zhao et al., 2001a, b, 2007, 2012a, c). This section satisfies all of the geological and biostratigraphic requirements for a GSSP (see Remane et al., 1996). Among the criteria that must be considered in the selection of a GSSP, biostratigraphic, chemostratigraphic, paleogeographic, facies-relationship, and sequence-stratigraphic data are all available for the Wuliu-Zengjiayan section (Zhang, et al., 1996; Yuan et al., 1997, 1999, 2002; Yin and Yang, 1999; Peng et al., 2000a,b; Zhao et al., 2001a, b, 2004, 2005; 2006, 2007, 2012a, c , 2014, 2015; Guo et al., 2005, 2010a, b, 2014; Wang et al, 2006;Yin et al., 2010; Sundberg et al., 2010, 2011; Gaines et al., 2011) and are summarized below. The section is easily accessible, and access for research is unrestricted in all seasons. The Wuliu-Zengjiayan section is located in the Miaoling National Geopark, which is under permanent protection by the government of Jianhe County, Guizhou Province, China. The Cambrian Kaili Formation at the proposed stratotype section contains the Kaili Biota, a well-known Burgess Shale-type biota that has been the subject of a great deal of prior research by numerous geoscientists (Yuan et al., 1999; Zhu et al., 1999, 2006; Zhao et al., 2001a, b, 2005, 2011, 2012c; Yang Y. et al., 2016; Yang X. et al., 2017). Governmental protection ensures continued free access to the site for research purposes.

Proposal: Wuliu-Zengjiayan section at Balang Village, Jianhe County, in the Miaoling Mountains, eastern Guizhou Province, China as the GSSP for the base of the Miaolingian Series and Wuliuan Stage

1. Stratigraphic rank of the boundary

The proposed Miaolingian Series will be the third series of the Cambrian System, and the proposed Wuliuan Stage will be the lowermost stage of the Miaolingian Series (Figs. 1, 2). The base of the series and stage, once ratified, will automatically define the common top of provisional Cambrian Series 2 and its uppermost stage, which are also yet unnamed. The boundary will be a standard series/epoch and stage/age GSSP. The Miaolingian Series and the Wuliuan Stage, proposed for global use, have the same lower boundary as the Wulingian Series and the Taijiangian Stage

(Peng et al., 2000a) as used in South China. The upper boundary of the series is defined by the base of the Furongian Series, and the upper boundary of the stage is defined by the base of the Drumian Stage of the Miaolingian Series (Fig. 1).

The name of Wuliuan and Miaolingian are derived from geographic localities in Jianhe, Guizhou, where the proposed GSSP is located. The name of Wuliuan Stage (and Age) is derived from Wuliu, a small hill that forms the Wuliu-Zengjiayan section, 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.

2. Proposed GSSP – geography and geologic setting

2.1. Geographic location

The Wuliu-Zengjiayan section (Yuan et al., 1997, 1999, 2002; Zhao et al., 2001a, b, 2004, 2007; 2012a, c) is situated along a hill ridge, which is about 0.5 km northwest of Balang Village, Jianhe County (formerly Taijiang County), Guizhou Province, China (Fig. 3A, B, C). The Cambrian Kaili Formation crops out extensively in the Balang and Chuandong areas (Fig. 4). The studied area lies in the southwest of the Miaoling National Geopark, to which it belongs (Fig. 3D). The proposed boundary stratotype section for defining the base of the Miaolingian Series and the Wuliuan Stage lies in the lower part of the Kaili Formation at the Wuliu-Zengjiayan section. 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 (Fig. 3B). The position of the proposed section is on topographic map G-49-37-55 (Surveying and mapping Bureaus of Guizhou and Shaanxi, 1991, Dagaowu Area 1:10000 scale; Fig. 3C), and the proposed GSSP is exposed near the ridge crest at a position of 26^{o}44.843’N latitude and 108^{o}24.830’E longitude at an elevation of approximately 795 m.

2.2. Geological location

The Cambrian geology of eastern Guizhou, including the site of the proposed 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 eastern 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 in the Nanhua fold belt and belongs to the north limb of the southwestern portion of the Shansui Syncline. 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). Exposure of Neoproterozoic and Cambrian strata in the Jianhe area is excellent. The Precambrian succession there consists of several formations, which, in ascending order, are the Liangjiahe, Tiesiao, Datangpo, Nantuo, Doushantuo, and Dengying formations (the former three units are marked as Cy_{l+t+d} on Fig. 4). The Cambrian succession in this area comprises seven units. In ascending order these are the Niutitang, Bianmachong, Balang, Tsinghsutung, Kaili, Jialao and Loushanguan formations (Fig. 4). 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), notably Yuan et al. (2002). An overview of Cambrian paleogeography, biotic provinces, and geologic history of the region was provided by Peng and Babcock (2001).

The Kaili Formation, which is the subject of this proposal, is exposed widely in eastern and southeastern Guizhou, showing a NE–SW trend across the Danzhai, Taijiang, 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; Wang et al., 2006; Gaines et al., 2011), where it overlies either the Wuxun Formation or the Tsinghsutung Formation and is overlain by the Jialao Formation. The formation is typically about 300 m thick, and straddles the boundary of the provisional Cambrian Series 2 and the proposed Miaolingian Series. The Kaili Formation contains a total of 62 trilobite genera (subgenera) with 38 genera occurring below the proposed boundary and 44 genera occurring above it: 20 genera range through the proposed boundary (Zhao et al., 2001a, b; Yuan et al., 2002). Trilobites are commonly articulated, thin shelled, broad and of low convexity, indicating a relatively deep, quiet water sedimentary environment (Zhang et al., 1996; Zhu et al., 1999; Yuan et al., 2002; Wang et al., 2006; Gaines et al., 2011).

2.3 Location of level and specific point

The boundary interval of the Wuliu-Zengjiayan section consists primarily of silty and calcareous mudstones (Fig. 7) that are abundantly fossiliferous and bear the first appearance datum (FAD) of the widely distributed oryctocephalid trilobite *Oryctocephalus indicus*（Fig. 8A–D）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*, *Oryctocephalina*, *Euarthricocephalus* (*Microryctocara*), *Burlingia* and *Olenoides*. Below the proposed GSSP level, the *Bathynotus kueichouensi-Ovatoryctocara sinensis* Assemblage-Zone is recognized (Figs. 6A, 7). Within this zone, many trilobites with broad geographic ranges are present, including taxa belonging to *Bathynotus*, *Redlichia*, *Oryctocephalops*, *Oryctocephalites* and *Ovatoryctocara* (Yuan et al., 1997, 2002; Zhao et al., 2001a, b, 2007, 2012a, c; Sundberg et al., 2011; Fig. 7). Given its excellent and well-resolved record of this important global turnover in trilobite faunas within a consistent depositional environment, the FAD of *Oryctocephalus indicus* in the Wuliu-Zengjiayan section is proposed herein as the GSSP for defining the base of the Cambrian Miaolingian Series and Wuliuan Stage.

2.4 Stratigraphic completeness

Detailed bed-by-bed correlation of the proposed Miaolingian Series through eastern Guizhou, coupled with high-resolution 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; Yin et al., 2010; Sundberg et al., 2010, 2011), sedimentology (Zhang et al., 1996; Wang et al., 2006; 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 demonstrates the stratigraphic continuity of the basal interval of the proposed Miaolingian Series and Wuliuan Stage. 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; 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 continuous deposition of a succession of shales and subordinate lime mudstones across the proposed GSSP boundary interval (Yuan et al., 2002; Zhao et al., 2005, 2007, 2012a, c; Sundberg et al., 2010, 2011; Gaines et al., 2011). The section lacks syndepositional and tectonic disturbance at the proposed GSSP boundary interval, although minor bedding-plane slippage occurs along some beds, which is expected in an inclined succession of 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. 7). Although the section has been affected by mild oxidative weathering, no evidence of significant diagenetic alteration or metamorphism is present.

2.5 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 thinly bedded limestones with shale interbeds, with a thickness of 23.7 m (bed nos. 1–5); the middle part, including the *Oryctocephalus indicus* Zone and the well-known Kaili Biota (Zhao et al., 2005, 2011), is 150.43 m thick (bed nos. 6–27), and is dominated by calcareous shales; the upper part includes most of the *Peronopsis taijiangensis* Zone and consists of thinly bedded limestone layers grading into grainy limestone with a thickness of 40.07 m (bed nos. 28–30; Fig. 7).

The proposed GSSP for the base of the Miaolingian Series and the Wuliuan Stage occurs in a succession of greenish-grey silty mudstone and shale in the basal middle part of the Kaili Formation (Fig. 6B–D). The strata below the proposed GSSP belong to the upper Duyunian Stage in the terminology used for South China.

2.6 Provisions for conservation, protection, and accessibility

The exposure containing the proposed GSSP in the Balang area received protection from the government of Guizhou in 2001 due to its geological significance. Building, landscaping or other destruction of the exposure is permanently prohibited. In 2009, the Balang area was included as a part of the Miaoling National Geopark and is managed and protected by the government of 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 township of Jianhe County directly to Balang or Tunzhou villages in no more than 20 minutes. The proposed stratotype section is easily accessed within 20–30 minutes from either village, via paved walking paths.

3. Motivation for selection of the boundary level and of the potential stratotype section

3.1 Principal correlation event (marker) at proposed GSSP level

The oryctocephalid trilobite *Oryctocephalus indicus* (Reed, 1910) (Fig. 8A–D) has been revised in detail (Jell and Hughes, 1997; Sundberg and McCollum, 1997; Yuan et al., 1997; Zhao et al., 2006) and has been accepted as one of the tools for defining the base of provisional Stage 5 (Geyer and Shergold, 2000; Peng et al., 2000a, b; Shergold and Geyer, 2001, 2003; Zhao et al., 2001a, b, 2004, 2012a, b, c, 2014; Yuan et al., 2002; Peng, 2003; Sundberg and McCollum, 2003; Babcock et al., 2005; Korovnikov, 2006; Fletcher, 2007; Luo et al., 2009; Sundberg et al., 2010, 2011, 2016; Yuan and Ng, 2014; Hughes, 2016; ISCS, 2016; Singh et al., 2016; Esteve et al., 2017; Zhao et al., 2017). *O. indicus* has an intercontinental distribution (Reed, 1910; Saito, 1934; Jell and Hughes, 1997; Sundberg and McCollum, 1997; Yuan et al., 1997, 2002; Zhao et al., 2001a, b; Korovnikov, 2001, 2006; Luo et al., 2009) and its first appearance has been acknowledged as the most favorable level for the GSSP defining the base of a global stage (Jell and Hughes, 1997; Sundberg and McCollum, 2003; 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; Yuan et al., 2002; Peng, 2003; Babcock et al., 2005, 2014; Peng et al., 2006, 2012a; McCollum and Sundberg, 2007; Geyer and Peel, 2011; Hughes, 2016; Singh et al., 2016; Esteve et al., 2017; Zhao et al., 2017). The species has been recognized from Siberia (Molodo River section, upstream of Lena River, Siberia; Korovnikov, 2001, 2006; Zhao et al., 2006; Fletcher, 2007; Shabanov et al., 2008; Hughes, 2016; Esteve et al., 2017), North India (Parahio and Pin valleys sections, Spiti region; Jell and Hughes, 1997; Hughes, 2016; Singh et al., 2016), the western USA (eastern Split Mountain section, Nevada and Saline Range section, California; Sundberg and McCollum, 1997, 2003), North Greenland (Fimbuldal section, Peary Land; Geyer and Peel, 2011) and North Korea (near Ssukkol, Heukkyon, Hwanghai-do; Saito, 1934).

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; Yuan and Ng, 2014; Sundberg et al., 2010, 2011, 2016; Geyer and Peel, 2011; 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. *O. americanus*, which occurs in the underlying *Amecephalus arrojosensis* Zone (Sundberg and McCollum, 2003), closely resembles *O. indicus*; specimens assigned to *O. americanus* lack connected transglabellar furrows (S2, S3), apparently as a result of taphonomic bias. Zhao et al. (2006, 2007) and Esteve et al. (2017) interpreted *O. americanus* as a junior synonym of *O. indicus*, one that shows the primitive form of this taxon. Sundberg (personal communication, 2008) suggested that the advanced form of *O. indicus* was derived from *O. americanus*. 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 0.8 m above the LAD of *Redlichia* (Zhao et al., 2001a). In the western United States, the FAD of *O. indicus* or *O. americanus* succeeds the disappearance of *Olenellus*. *O. indicus* is one of the signature taxa characterizing the recovery after the Hawke Bay Event (Palmer and James, 1980; Tong, 1995; Bowring and Erwin, 1998), an extinction event occurring at the end of the Cambrian Series 2. 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 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 *Olenoides* and *Burlingia* in the *Oryctocephalus indicus* Zone, and *Bathynotus*, *Ovatoryctocara* and *Redlichia* in the *Bathynotus kueichouensis-Ovatoryctocara sinensis* Assemblage-Zone. This combination of taxa provides for precise stratigraphic correlation into the Mediterranean realm. 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 (Ahlberg, 1998; Álvaro et al., 2003, 2013; Gozolo et al., 2007; Sundberg et al., 2010; Geyer and Peel, 2011; Zhao et al., 2012a). With the aid of Siberian taxa, the base of the proposed Wuliuan Stage can be correlated with that of the Mediterranean region.

3.2. Potential stratotype section and point

The FAD of *Oryctocephalus indicus* in the Wuliu-Zengjiayan section, Guizhou Province, China, occurs at a level of 52.8 m above the base of the Kaili Formation (Fig. 8A; Zhao et al., 2001a, b, 2006, 2007, 2008, 2012a, 2014; Sundberg et al., 2010, 2011). This position, 52.8 m above the base of the Kaili Formation in the Wuliu-Zengjiayan section, is the intended GSSP section and point.

The Kaili Formation in the Wuliu-Zengjiayan section is a mostly monofacial succession of calcareous shales with subordinate gray limestone-marlstone in the basal and 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 proposed GSSP, suggesting deposition on a gentle slope. The interval of the FAD of *O. indicus* is inferred to be a maximum flooding surface representing a major eustatic transgression (Zhu et al., 1999; Wang et al., 2006; Gaines et al., 2011; Fig. 11).

The Kaili Formation contains 62 genera and subgenera of trilobites (Yuan et al., 2002) and embraces three trilobite zones, including two polymerid zones and one agnostoid zone (Zhao et al., 2012a, c, 2015), in ascending order: the *Bathynotus kueichouensis*-*Ovatoryctocra sinensis* Assemblage-Zone (4.0–52.8 m above the base of the Kaili Formation, Fig. 7), the *Oryctcocephalus indicus* Zone (52.8–143.78 m above the base of the Kaili Formation, Fig. 7), and the *Peronopsis taijiangensis* Zone (143.78–214.2 m above the base of the Kaili Formation, Fig. 7). 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, a level that is here proposed for defining the base of the Miaolingian Series and Wuliuan Stage. 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. 7). Current stratigraphic resolution suggests that the FAD of *O. indicus* in the major Cambrian realms is equivalent in age. In the Wuliu-Zengjiayan section, *O. indicus* ranges across a 90.98 m interval, which is highly fossiliferous throughout. The high-resolution data on distributions of trilobite taxa through the boundary interval of the proposed GSSP in the Wuliu-Zengjiayan section are summarized in Figure 7. 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 trilobites from the boundary interval, the LADs of *Ovatoryctocara sinensis* (51.6 m above the base of the Kaili Formation, Figs. 7, 8F), *Bathynotus kueichouensis* (51.6 m above the base of the Kaili Formation, Figs. 7, 8G–H), and *Peronopsis taijiangensis* (143.78 m above the base of the Kaili Formation, Fig. 7) 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 exceptionally preserved Burgess-type biota, termed the Kaili Biota, occurs above the FAD of *Oryctocephalus indicus*. Representatives of at least 11 phyla, including algae, sponges, chancelloriids, cnidarians, “worms”, tardipolypods, medusiform fossils, brachiopods, molluscs, arthropods, echinoderms and various problematic fossils, are present in the Kaili Biota, and many of them are non-biomineralizing (Zhao et al., 2005, 2011; Fig. 12). As indicated by Zhu et al. (2006), the general stratigraphic position of the Kaili Lagerstätte marks an interval of time in which various local environmental factors were suitable for globally exceptional preservation. Thus, the position of the non-biomineralizing fossils also can be useful for constraining the position of the proposed base of the Miaolingian Series and Wuliuan Stage.

Beside trilobites and the exceptionally preserved taxa of the Kaili Biota, the acritarch assemblage from the proposed stratotype Wuliu-Zengjiayan section shows a prominent change at the FAD of *Oryctocephalus indicus* (Yin and Yang, 1999; Yang and Yin, 2001; Yin et al., 2009, 2010; Fig. 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 coincides almost exactly 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. 6B, 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 detail (Volkova, 1990; Moczydłowska, 1998, 1999; Palacios, 2015; Moczydłowska and Yin, 2012).

3.3 Demonstration of regional and global correlation

The FAD of *Oryctocephalus indicus* in the proposed 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., 2000a; 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 as follows:

3.3.1 Polymerid trilobite biostratigraphy

Two polymerid biozones are recognized in the Wuliu–Zengjiayan section (Zhao et al., 2001a, b, 2012a, c, 2015; 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. 6, 7). 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 (Luo et al., 2009), and occurs in the Parahio Member of the Kunzam La Formation in Parahio Valley, Spiti area of India (see Singh et al., 2016), and the corresponding level in northwestern Korea (Saito, 1934).

The trilobites from these polymerid zones provide correlation tools of regional or intercontinental scale that allows us to tie into most Cambrian faunal realms. Particularly useful guides fossils are planktonic trilobites such as *Oryctocephalus* (Reed, 1910; Saito, 1934; Lermontova, 1940; Shergold, 1969; Lu et al., 1974a, b; 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; Hughes, 2016; Singh et al., 2016; Esteve et al., 2017), *Olenoides* (Kobayashi, 1935; Babcock, 1994; Yuan et al., 2002; Geyer and Peel, 2011; Sundberg et al., 2011; Wang et al., 2016), and *Burlingia* (Zhang et al., 1980; Whittington, 1994; Yuan et al., 2002; Yuan and Esteve, 2015); and nektobenthic trilobites such as *Redlichia* (Kobayashi, 1935; Lu, 1950; Öpik, 1970; Zhang et al., 1980; Guo et al., 1999; Yuan et al., 2002; Kruse et al., 2004; Hughes, 2016; Laurie, 2016) and *Bathynotus* (Kobayashi, 1935; Lu and Chien, 1964; Whittington, 1988; Shergold and Whittington, 2000; Peng J. et al., 2009, 2014; Webster, 2009; Goryaeva et al., 2012).

3.3.2 Agnostoid trilobite biostratigraphy

A single agnostoid biozone, the *Peronopsis taijiangensis* Zone, is recognized in the biostratigraphic succession of the Wuliu-Zengjiayan section, lying immediately above the *Oryctocephalus indicus* Zone. In eastern Guizhou and western Hunan, it is overlain by the agnostoid *Ptychagnostus gibbus* Zone of the Huaqiao Formation. *P. taijiangensis* is closely similar to *Peronopsis recta* Pokrovskaya and Egorova, 1972, which is associated with *Oryctocephalus reticulatus* in the *O. indicus* Zone（previously the *Kounamkites* Zone） of the Kuonamka Formation in the Molodo River section, Siberia. In Laurentia, the *Ptychagnotus praecurrens* Zone, followed by the *P. gibbus* Zone, correlates with the upper half of the *Oryctocephalus* or *O. indicus* Zone (Robison and Babcock, 2011). *Ptychagnotus praecurrens* is a widespread agnostoid trilobite, known from Sweden, Norway, England, Canada (British Columbia), Poland, Russia (Siberia), Australia, and the USA (Utah and Nevada) (Westergård, 1946; Rushton, 1966; Egorova et al., 1976; Robison, 1982; Ahlberg, 1989; Sundberg, 2011; Laurie, 2004, 2016; McCollum and Sundberg, 2007; Naimark, 2008; Shabanov et al., 2008; Kruse et al., 2009; Weidner and Ebbestad, 2014), and probably from

Kazakhstan (Ergaliev and Ergaliev, 2008). Although *P. praecurrens* has been not recorded in South China (likely due to facies restriction), strata corresponding to the *P. praecurrens* Zone are present: the Aoxi Formation, which is underlain by the Huaqiao Formation in northwestern Hunan, and the Jialao Formation, which is overlain by the Kaili Formation in southeastern Guizhou, are composed of grey to light grey thin-bedded to thick bedded dolomites. In the Wuliu-Zengjiayan section, the eodiscid trilobite *Pagetia significans* makes its first appearance at the same level as the FAD of *O. indicus* (Yuan et al., 2002). *P. significans* has been recorded from the Miaolingian Series strata of Australia (Jell, 1975), North Korea (Kobayashi, 1944) and northern India (Jell and Hughes, 1997; Singh et al., 2016).

3.3.3 Acritarch biostratigraphy

As phytoplanktic microfossils, Cambrian acritarchs are of significance to assist in delineating faunal zones, for indicating changes in 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 (0–52 m from the base of the Kaili Formation); and the *Cristallinium cambriense – Heliosphaeridium nodosum–Globosphaeridium cerinum* assemblage (52–140 m from the base of the Kaili Formation) are recognized in the Wuliu-Zengjiayan section. These assemblage zones are based on continuous samplings 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 *Heliosphaeridium dissimilare, H. nodosum, H. serridentatum, Globosphaeridium cerinum* and *Solisphaeridium flexipilosum* (Fig. 10), exhibit a first appearance at the same bed simultaneously (52. 3–52. 7 m from the base of the Kaili Formation), which is slightly below the proposed GSSP for the base of proposed Miaolingian Series and Wuliuan Stage.

Acritarch forms occurring in the Wuliu-Zengjiayan section, for example, *Heliosphaeridium nodosum, H. dissimilare, H. serridentatum, Globosphaeridium cerinum, Solisphaeridium frixipilosum,* also mark the base of the traditional middle Cambrian elsewhere in Baltica, and

Gondwana (Volkova, 1990; Moczydłowska,1998, 1999; Moczydłowska and Yin, 2012; Palacios, 2015). On the basis of the present record and the known data, it is noted that many species of genus *Heliosphaeridium* are known from strata belonging to provisional Cambrian Series 2 and the proposed Miaolingian Series or even restricted to the Miaolingian Series. Therefore, some species of *Heliosphaeeridium*, such as *H. dissimilare* and *H. serridentatum*, appear to be characteristic of 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), northwestern Himalaya, India and the Log Cabin Mine section, Highland Range, Pioche-Caliente area, eastern Nevada, USA (Yin et al., 2013), showing the obvious acritarch taxonomic change near the base of Miaolingian Series and Wuliuan Stage at the FAD of *Oryctocephalus indicus*. Such a change is significant and indicates an important geobiological event (Yin et al., 2016; Fig. 11).

3.3.4 Chemostratigraphy

3.3.4.1 Carbon isotope chemostratigraphy

The carbon isotopic composition of carbonate carbon varies between –2.7 and +3.1 ‰ in the Wuliu-Zengjiayan section (Yang et al., 2003; Guo et al., 2005, 2010a, b). The base of the *Oryctocephalus indicus* Zone is marked by a distinctive shift in carbon isotopic values, near the peak of a rather long negative $\delta^{13}C_{carb}$ excursion with minimum values of –2.7‰ (Fig. 11). 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 base of the proposed Miaolingian Series/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), and North America (Montañez et al., 2000) and at localities elsewhere in the world (Guo et al., 2010a, b).

3.3.4.2 Sulfur isotope chemostratigraphy

The sulfur isotopic composition of sedimentary pyrite displays a similar variation across the provisional Cambrian Series 2 through the proposed Miaolingian Series from 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 is followed by an interval containing nodular limestones. Above these nodular limestones, there is a shift from $\delta^{34}S_{CRS}$ values around 2.7 ‰ to 37.3 ‰ through the upper part of the section. 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).

3.3.4.3 Organic chemostratigraphy

Recently, an organic geochemical investigation has been completed for the boundary interval (Beds 8–12) of the Wuliu-Zengjiayan section (Wang et al., 2014). Figure 11 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 provisional Cambrian Series 2–proposed Miaolingian Series boundary at the top of Bed 9. An abrupt change in $\delta^{13}C_{org}$ occurs across the boundary, which is consistent with the excursion in $\delta^{13}C_{carb}$ (Guo et al., 2010a, b). 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 proposed Wuliuan Stage.

In general, changes observed are interpreted to reflect primary depositional values, notably variations in the global burial rates of organic matter. These, in turn, are linked to biological changes and a possible regional and global anoxia–extinction event across the transition from the Cambrian Series 2 to the Miaolingian Series and Wuliuan Stage. The extinction of multiple trilobite species at the end of Series 2 is closely related to isotopic excursions of both carbon and sulfur (Guo et al., 2010a, b, 2014; Fig. 11), and the molecular chemostratigraphic evidence also strongly supports the placement of the base of the proposed Miaolingian Series and Wuliuan Stage.

3.3.5 Sequence stratigraphy

Sea level changes corresponding to 3rd and 4th order depositional cycles (Fig. 11) 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 proposed boundary at 52.8 m above the base of the formation (the FAD of *Oryctocephalus indicus*; Gaines et al., 2011). The remaining thickness of the middle and upper Kaili Formation is interpreted as a highstand system tract with gradual shallowing accompanying seaward progradation of the Yangtze carbonate platform, manifested as 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 represent a complete 3rd order depositional cycle, representing transgression, maximum flooding, and a protracted period of regression accompanied by basin filling (Wang et al., 2006).

4. Other regional candidate sections and reasons for rejection

For comparative purposes, the Jianshan and Sanwan sections of 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. However, there is a small tectonic fold that occurs within the *O. indicus* Zone in the Jianshan section (at *ca*.78.5 m above the base of the Kaili Formation) (Zhao et al., 2008). The Sanwan section appears to be a good complement to the proposed GSSP section. It has received less intensive international study, so fewer correlation tools have been applied to it.

5. Extraregional sections

Two extraregional sections were considered as potential stratotype sections for the GSSP of the Wuliuan Stage. Both are well exposed, well documented, have an inferred complete succession of strata through the base of the *Oryctocephalus indicus* Zone, and meet the major requirements for a GSSP. Both are located in major Cambrian faunal realms. The Cambrian Subcommission considers extraregional sections to be important for correlation purposes both regionally and globally.

The first extraregional section occurs along the right bank of Molodo River on the southeastern slope of the Olenek Uplift of Siberian Platform, approximately 20 km downstream of the Daldy-Molodinsky Creek (69^{o}29`27``N and 122$^{o}$16`47``E). It exposes a complete succession of strata across the base of the *Oryctocephalus indicus* Zone. Here, the Kuonamka Formation is *ca*. 50 m thick with abundant trilobites, and is subdivided into 7 biozones (Shabanov et al., 2008). These zones in a thin succession reveal a condensed depositional succession. However, the Molodo River section is well exposed and lacks significant tectonic disturbance. In the section, trilobite collections are relatively of high-resolution, and the taxa have been well studied and illustrated (see Shabanov et al., 2008). *O. indicus* appears first at 20.4 m above the base of the Kuonamka Formation at the base of *O. indicus* (= *O. reticulatus*) Zone, which overlies the *Ovatorytocara* Zone. Important trilobites of the *O. indicus* Zone include *Kounamkites virgatus*, *K. rotundatus*, *Oryctocephalus indicus*, *O. vicinus*, *Pagetia ferox*, and *Peronopsis recta*, whereas *Anabaraspis splendens*, *Ovatoryctcara granulata*, *O. ovata*, *Cheiruroides arcticus*, *Oryctocephaalops frischenfeldi*, *Pagetides spinosus*, *Paradoxides pinus*, and *P. eopinus* are known from the *Ovatoryctcara granulata* Zone (Shabanov et al., 2008). These trilobites provide a good reference for global correlation of the base of the proposed Miaolingian Series and Wuliuan Stage. The Molodo River section is condensed. It is also located in a remote area, and access to it is rather difficult.

The second extraregional section lies on the eastern slope of Split Mountain, Nevada, Great Basin, USA (Sundberg and McCollum, 1997, 2003). It is also a good section with potential for a GSSP defining the provisional Stage 5. The FAD of *Oryctocephalus indicus* in the Split Mountain section is 15 m above the base of the Emigrant Formation (Sundberg et al., 2011), corresponding to the base of the proposed Wuliuan Stage. The section contains a succession that was continuously deposited in an outer-shelf to possible upper slope environment, and appears to be rather condensed (Sundberg and McCollum, 1997, 2003; Sundberg, 2011). The Split Mountain section is fossiliferous for trilobites but acritarch study has not been carried out. However, the palynomorph assemblage from the proposed Miaolingian Series at the Log Cabin Mine section in the Pioche-Caliente area of eastern Nevada is characterized by cryptospore-like microfossils and rare diachronous leiosphere acritarchs (Yin et al., 2013).

The section provides good regional and global correlation for the base of the Wuliuan Stage, and is accessible for research.

The Cambrian Subcommission voted on two proposed GSSP sections: 1, the Wuliu-Zengjiayan section, Guizhou, China; and 2, the Split Mountain section, Nevada, USA. The Voting Members expressed a strong preference for the GSSP to be placed in the Wuliu-Zengjiayan section at 52.8 m above the base of the Kaili Formation for the Wuliuan Stage and Miaolingian Series. The first appearance of *O. indicus* in the Split Mountain section is intended to become the ASSP for the Wuliuan Stage and Maiolingian Series.

6. Best estimate of age for the base of the proposed Miaolingian Series and Wuliuan Stage

The age for the proposed base of the proposed 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., 2012a; 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 ages on zircons 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., 2012a; 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.

7. Results of voting and comments on the proposal from the International Subcommission on Cambrian Stratigraphy

7.1. Ballot item and voting results, ISCS

An email ballot on the proposal was distributed to Voting Members of the International Subcommission on Cambrian Stratigraphy in October 2017, and responses were tallied in November 2018. The issue as posed on the ballot (paraphrased) was: Should the provisional stage name Stage 5 and the previsional series name Series 3 be replaced with the name Wuliuan Stage and the name Miaolingian Series respectively, and designate the GSSP marking the base of the stage and the series at 52.8 m above the base of the Kaili Formation, a point coinciding with the first appearance of the oryctocephalid trilobite *Oryctocephalus indicus*, in the Wuliu-Zengjiayan section, Guizhou, China? Among votes received, the results were 78% in favor, 9% against, 3% abstaining. Twenty-three Voting Members responded; 18 voted ‘yes’ (Ahlberg, Álvaro, Babcock, Bagnoli, Choi, Gozalo, Jago, Kruse, McCollum, Moczydlowska-Vidal, Naimark, Peng, Pratt, Saltzman, Steiner, Webster, Zhang, Zhu), two voted ‘no’ (Elicki, Zylinska) and three voted ‘abstain (Geyer, Pegel, Popov). One Voting Member (Varlamov) did not respond.

7.2. Comments on the proposal from the ISCS

Some Voting Members of the Cambrian Subcommission had comments (October–November 2017) on the choice of boundary or the choice of stratotype section. Those comments are included here (with some spelling and grammatical errors corrected).

Álvaro, J. Javier: “The proposal accomplishes all the necessary requirements for the selection of a GSSP and offers, in my opinion, the best section at this moment.”

Babcock, Loren E.: “After considerable deliberation about all aspects of the Stage 5 base, I think the Cambrian Subcommission has arrived at the most reasonable and practical decision, which involves a GSSP in the Wuliu-Zengjiayan section, Balang Village, Guizhou, China, at a point coinciding with the FAD of

Oryctocephalus indicus. It may not be a perfect choice, but it is a pragmatic choice from the standpoint of global correlation. The section satisfies all the requirements for a GSSP. The guide fossil for the base of the stage, especially when taken in context with the various secondary chronostratigraphic tools available, allows the horizon containing the GSSP to be precisely correlated, or at least reasonably constrained, in most areas of the world."

Elicki, Olaf: " I already gave detailed explanation regarding this stratigraphic attempt in the ballot before (Sept. 2017). By exactly the same reasons (no chance to correlate over very large and very important palaeogeographice regions half the globe; strongly limited benefit; no accurateness; more problems afterwards) I cannot confirm the offered solution. Whereas in the September ballot there was no choice to decline (only one of two given levels and "abstain" was possible to tick off), here it is possible."

Jago, James B.: "As stated previously I am rather reluctant to use the first appearance of *Oryctocephalus indicus* as the basis for the base of Stage 5, largely for the reasons outlined by Gerd Geyer. However, I do not think that *Ovatoryctocara granulata* is any better. Both have a rather limited geographic distribution and, from a parochial point of view, neither occur in Australia. In addition there is a marked faunal turnover at the proposed GSSP level in the Kaili Formation section, thus suggesting a change in the depositional environment at this level. However, I think the time has come to make a decision and my vote is for the GSSP within the Kaili Formation section."

Kruse, Pierre: "While I am not enamoured of the proposed series and stage names (they present some difficulty in pronunciation, at least for anglophones), I must prefer the Guizhou candidate as GSSP. Some contributing factors:

1- The Nevada candidate is relatively condensed, and as well, the bulk of the upper part of the recognised *indicus* Zone is barren of trilobites, indicating some environmental ('facies') exclusion of the group within that interval. There are no such hiati in the Guizhou candidate.

2- Phytoplankton studies are available for the Guizhou candidate, but no phytoplankton have been recovered from the Nevada candidate.

3- Lingering contention as to whether *americanus* is synonymous with *indicus* leaves some uncertainty as to the actual FAD of the guide species in the Nevada candidate section.

4- Notwithstanding the comments of the Nevada proponents on p.12–13 of their proposal, the available C-isotope curve for the Nevada candidate is relatively incomplete. The recognised FAD of *indicus* in that section appears to coincide with a positive peak, which does not correlate well with the negative trough (ROECE) recognised at the FAD of *indicus* in the Guizhou candidate. Conversely, and perhaps not coincidentally, the FAD of *americanus* coincides with a trough.

None of these points are fatal to the Nevada candidate, but taken together they favour the Guizhou candidate."

Moczydlowska-Vidal, Malgorzata: "Following the majority votes for the Wuliuan Stage and Miaolingian Series, I agree on the GSSPs for these units."

Naimark, Elena: "I chosed YES as I undersood 1) the need to stop on a certain decision, 2) all positives and future advantages which would bring us the choice of Kaili. But my concern is left the same: With "*indicus*" as an index species, we will be able to correlate Siberian sections with the middle of *Kounamkites* zone as *Oryctocephalus reticulatus* in Siberia has a lower stratigraphic position than in Kaili; to drag the boundary to the upper level seems a bit artificial. Also Siberian startigraphy lacks *Peronopsis taijiangensis* - the index of the overlaying Kaili zone; thus, at the moment I don’t know how to apply the supposed global stratigraphic scheme to Siberian sections. Probably, we need to work harder?”

Pegel, Tatyana: “Russian researchers have always believed and believe that, from the levels considered and proposed as the lower boundary of the Series 3 and Stage 5 of the Cambrian in the global scale, the FAD of *Ovatoryctocara granulata* is more suitable for this role. And not only because its findings are known widely enough, but also because near the level of its appearance significant changes occur in the organic world, which are noted in many paleocontinents: the extinction of the group of reef-builders – archaeocyaths; the emergence of agnostoids - a group of organisms important for biostratigraphy in the upper half of the Cambrian; the origin of paradoxidids, traditionally considered as an indicator of a Middle Cambrian age in several countries of the world, and oryctocephalids, whose representatives are the two rival species – *Ovatoryctocara granulata* and *Oryctocephalus indicus.*

In my opinion, it is difficult to overestimate this complex of "minor or additional" data that open the possibility of a really wide correlation of the lower boundary of the Series 3 and Stage 5 using the FAD of *Ovatoryctocara granulata* (or another taxon from this stratigraphic interval, if it will appear in the process of further research). Therefore, I abstain from voting on the proposed option.”

Peng, Shanchi: “The Wuliu-Zengjiayan section is well studied and documented, and I believe it is the best section, so far as known, for a GSSP defining the base of Stage 5 and Series 3.”

Webster, Mark: “The difficulty with defining the horizon and the GSSP for the base of Stage 5 is well known, and the decision was necessarily going to be based on non-ideal data. The FAD of *Oryctocephalus indicus* has been voted as the best (or the least poor) option for the stage-defining horizon. Based on currently available data, the Wuliu-Zengjiayan section gets my vote for the GSSP. Given the ongoing debate regarding several key issues in this boundary interval—including species diagnoses and the nature of the carbon isotope curve—I hope that paleontological and geochemical research will continue after this vote is concluded. It will be interesting to see how the ISCS decision fares over the coming years.”

Zhang, Xingliang: “My opinion remains unchanged! The Wuliu-Zengjiayan section at Balang Village meets the basic requirements of a GSSP and is the best choice as currently understood.”

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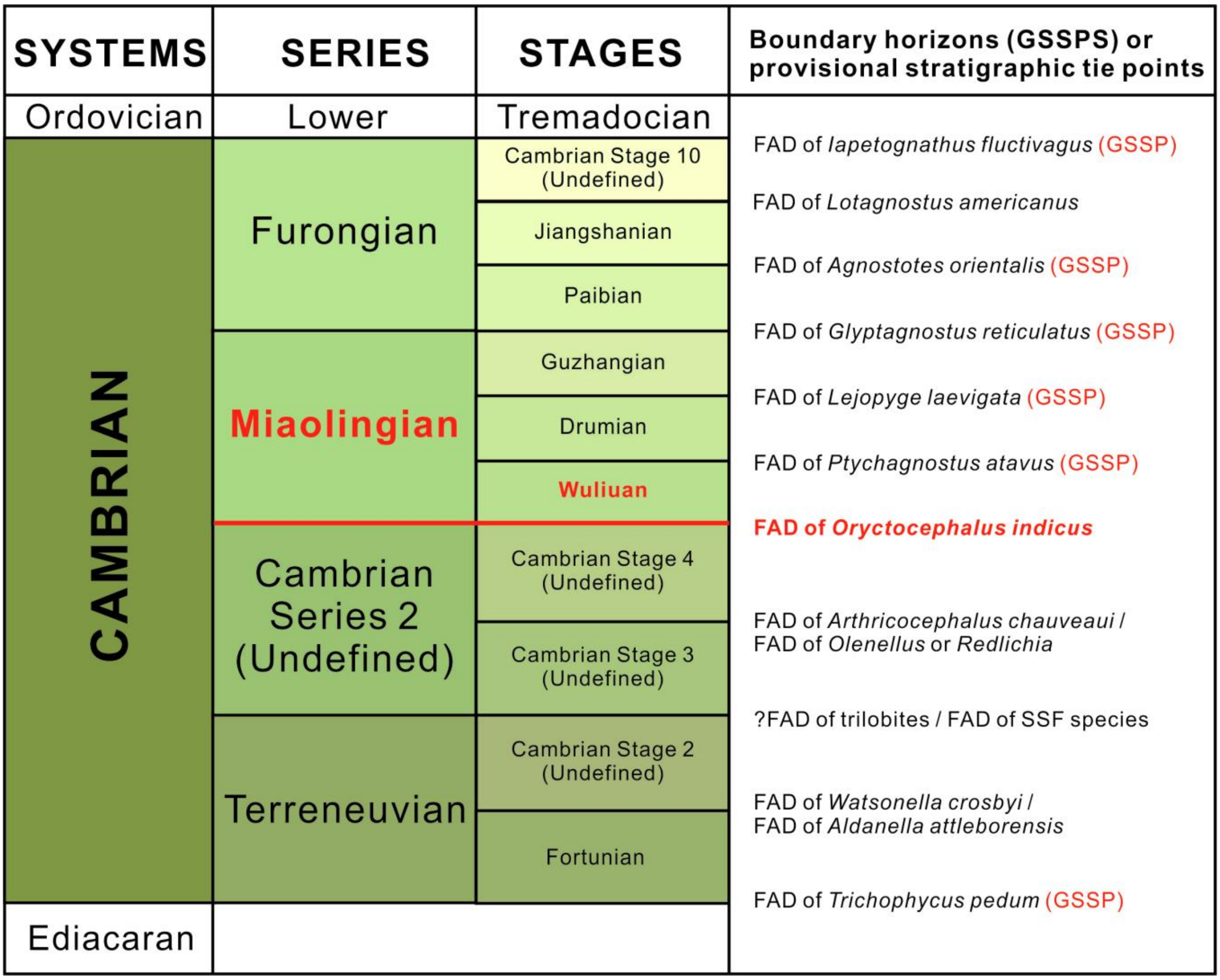

Fig. 1. Chart showing working model for global chronostratigraphic subdivision of the Cambrian System, indicating the lower boundary of the proposed Miaolingian Series and Wuliuan Stage (modified from Peng et al., 2007, 2012b).

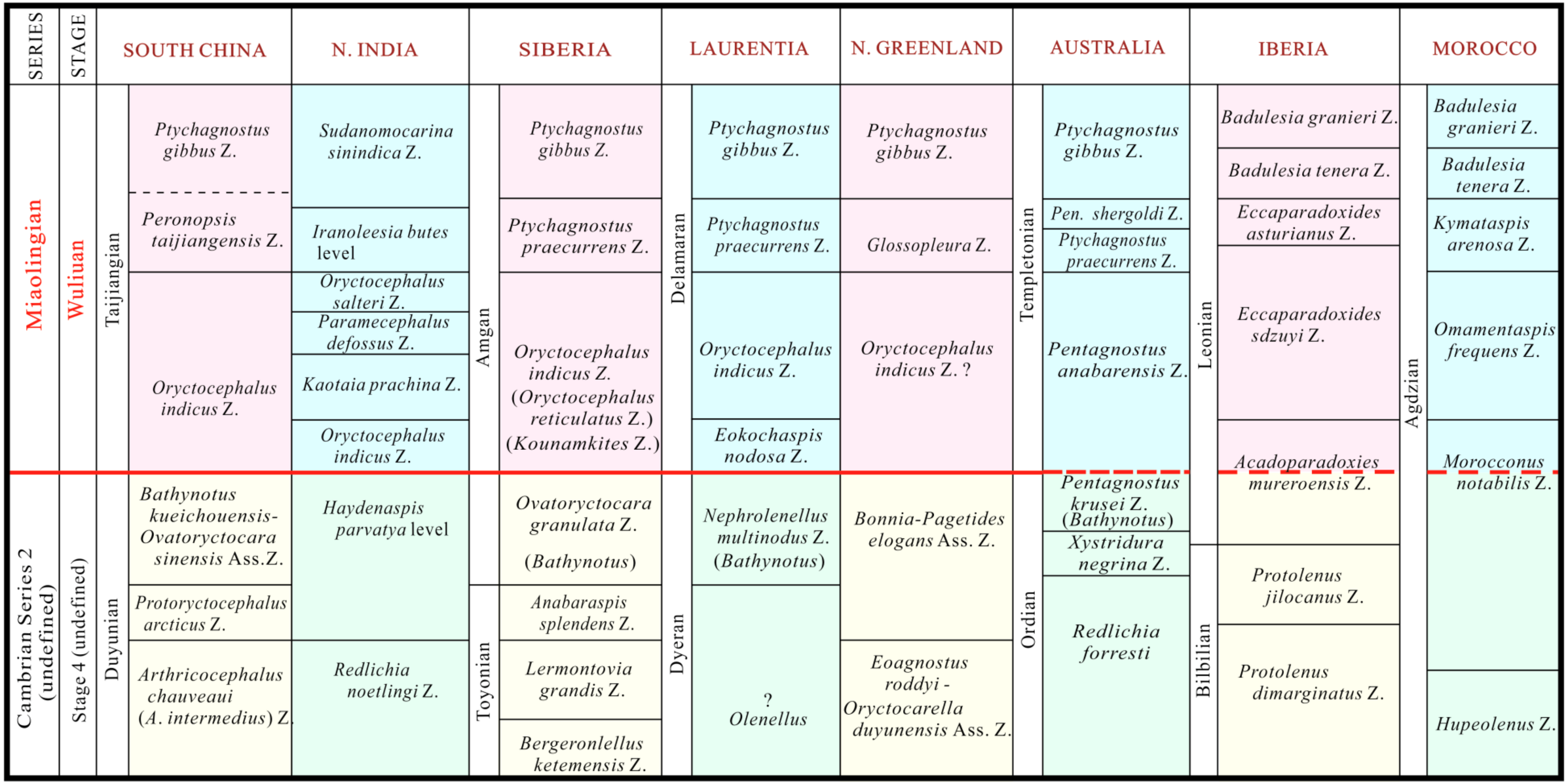

Fig. 2. Correlation chart of the proposed global chronostratigraphic Miaolingian Series and Wuliuan Stage below and above of boundary range of FADs and LADS of trilobites (Modified from Zhao et al., 2014). Chart compiled from numerous sources, summarized principally in Geyer (2015), Hughes (2016), Sundberg et al. (2016), Yuan and Ng. (2014), Zhao et al. (2015, 2017), Peng et al. (2017) and Esteve et al. (2017).

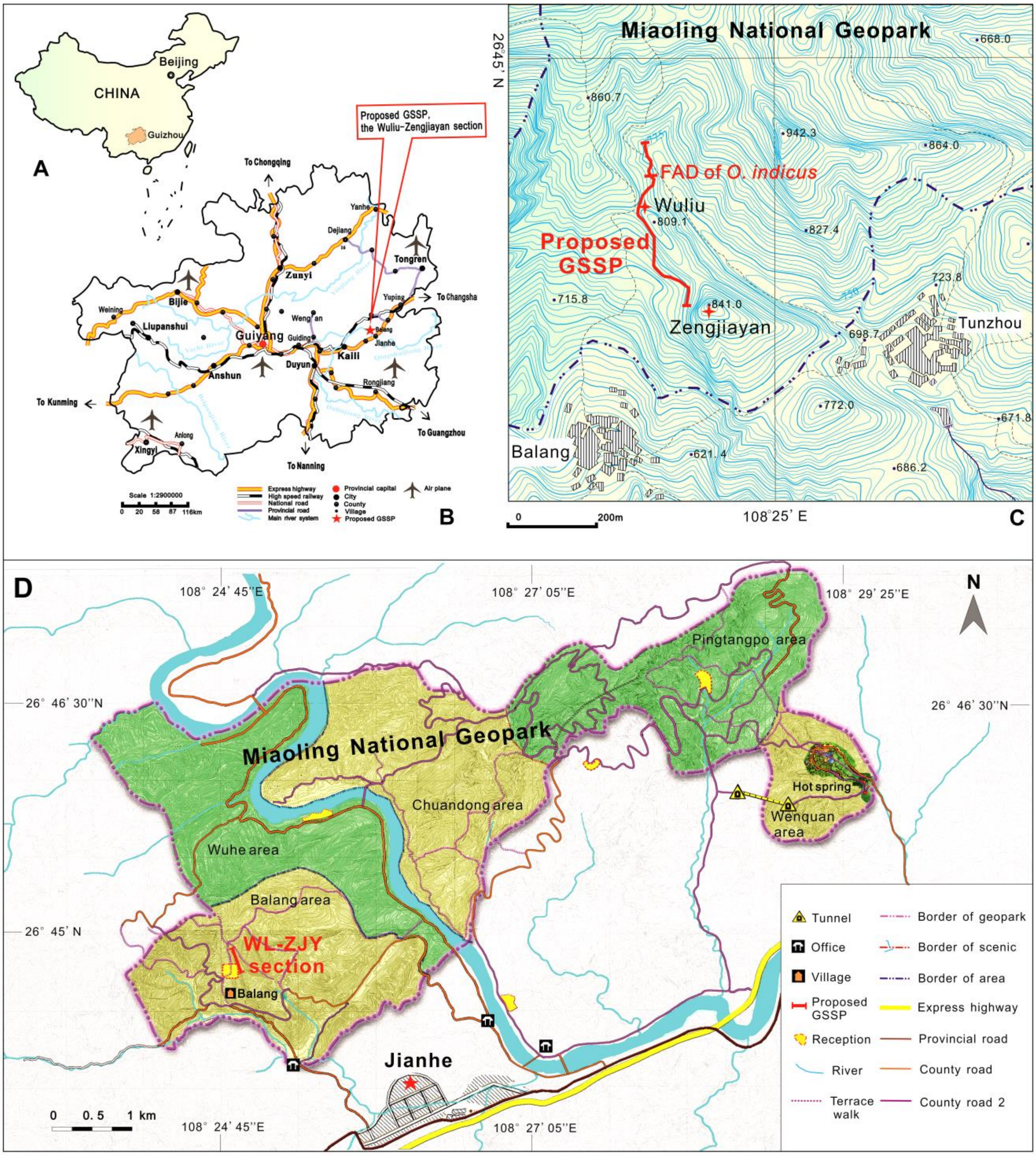

Fig. 3. Maps showing: A, Location of Guizhou, China (outlined by orange area); B, Road net and airports in Guizhou connecting to the proposed GSSP section, the Wuliu-Zengjiayan section (indicated by a red star); C, Topographic map of the proposed GSSP section with the FAD of *Oryctocephalus indicus* (modified from topographic map G-49-37-55, Dagaowu Area, drawn by Surveying and mapping Bureaus of Guizhou and Shaanxi, 1991; 1:10000 scale), and the Wuliu-Zengjiayan section is named after the Wuliu and Zengjiayan hills (indicted by red stars); D, Structure map of the Miaoling National Geopark with the proposed GSSP section (red bar) lying at the Balang area of the Geopark; noted that the section has been directly managed by the Geopark.

Fig. 4. Geological map of the study area and the location of the proposed stratotype section and point for the Miaolingian Series and Wuliuan Stage (modified from Bureau of Geology and Mineral Resources of Guizhou Province, 1990).

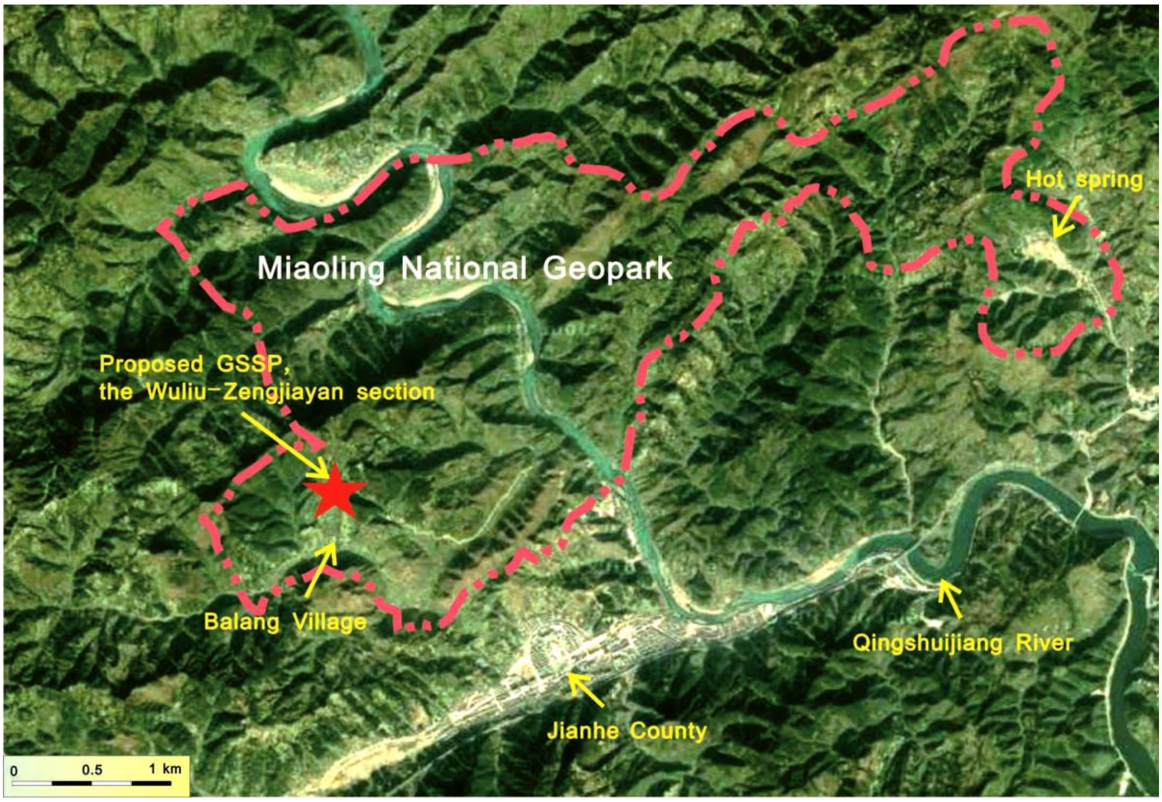

Fig. 5. Aerial photograph of the Miaoling National Geopark, Jianhe County with the proposed GSSP Wuliu-Zengjiayan section near Balang Village (indicated by a red star) for the Miaolingian Series and Wuliuan Stage.

Fig. 6. Exposure of the proposed GSSP for the base of the Wuliuan Stage (coinciding with the FAD of *Oryctocephalus indicus* in the Kaili Formation）at Wuliu-Zengjiayan section, Jianhe County, Guizhou Province, South China. Strata underlying the proposed GSSP belong to the upper part of undefined Cambrian Stage 4 of provisional Series 2. A, Overview of the Wuliu-Zengjiayan section showing three trilobites zones, in ascending order: *Bathynotus kueichouensis–Ovatoryctocara sinensis* Assemblage-Zone, *O. indicus* Zone, and *Peronopsis taijiangensis* Zone. B, Outcrop photograph of the proposed GSSP for the Miaolingian Series and Wuliuan Stage in the Wuliu-Zengjiayan section (the white marble markers of beds at right, the white line indicates the FAD of *O. indicus*), and the Wuliu Quarry at left (black gabbro markers) studied by Sundberg et al. has identical succession and fossil ranges with the proposal GSSP section (see Sundberg et al., 2011). C and D, close-up views of the rectangle areas in B, respectively, with indicating the position of the proposed GSSP (FAD of *O. indicus*). E, Outcrop within *O. indicus* Zone along with a terrace walk of the proposed GSSP where yields the Kaili Biota.

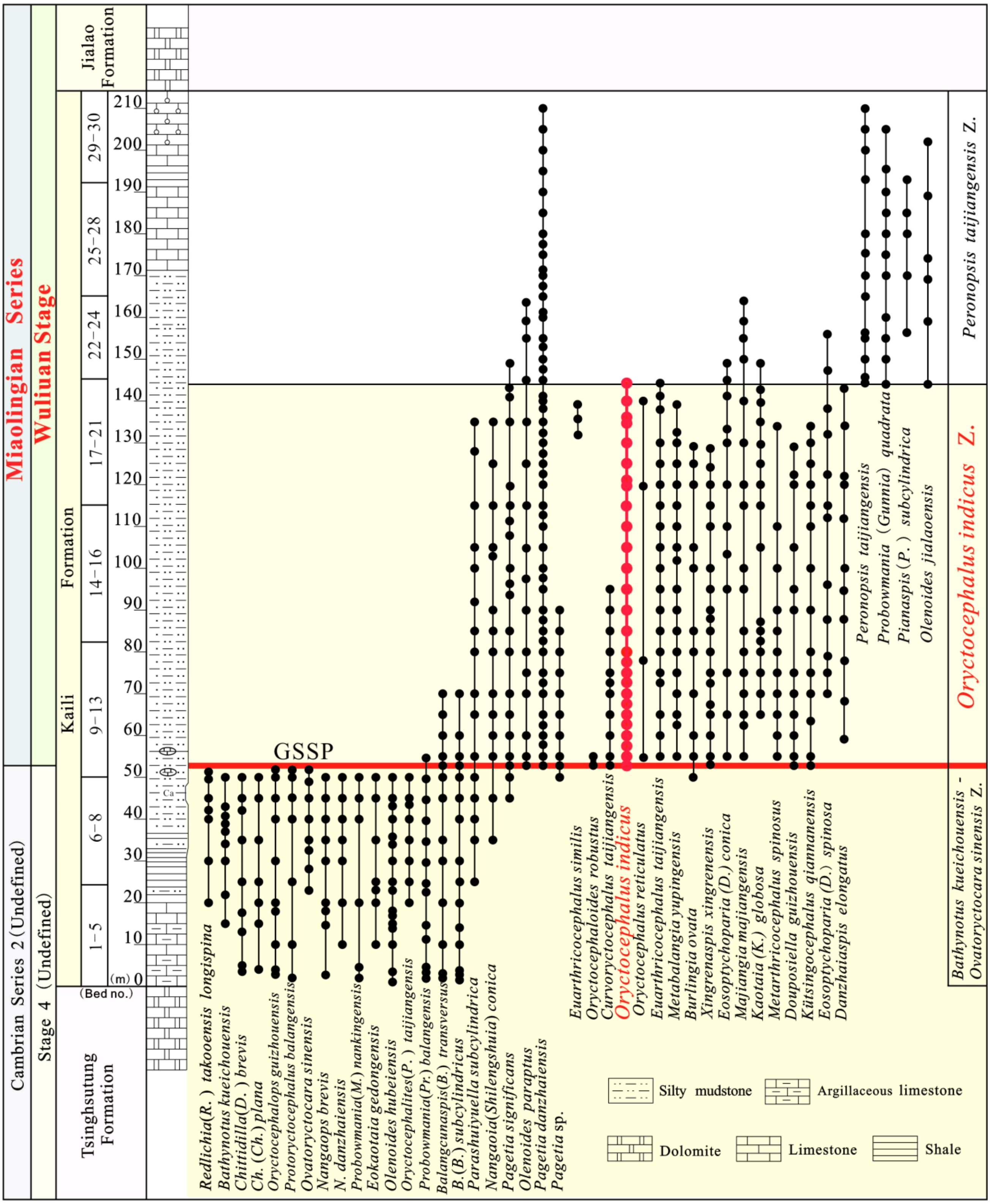

Fig. 7. Stratigraphic distribution of trilobite taxa and biostratigraphy of the Kaili Formation, Wuliu-Zengjiayan section, Jianhe County, Guizhou Province, South China. The proposed GSSP is located 52.8 m above the base of the Kaili Formation, and coincides with the base of the *Oryctocephalus indicus* Zone.

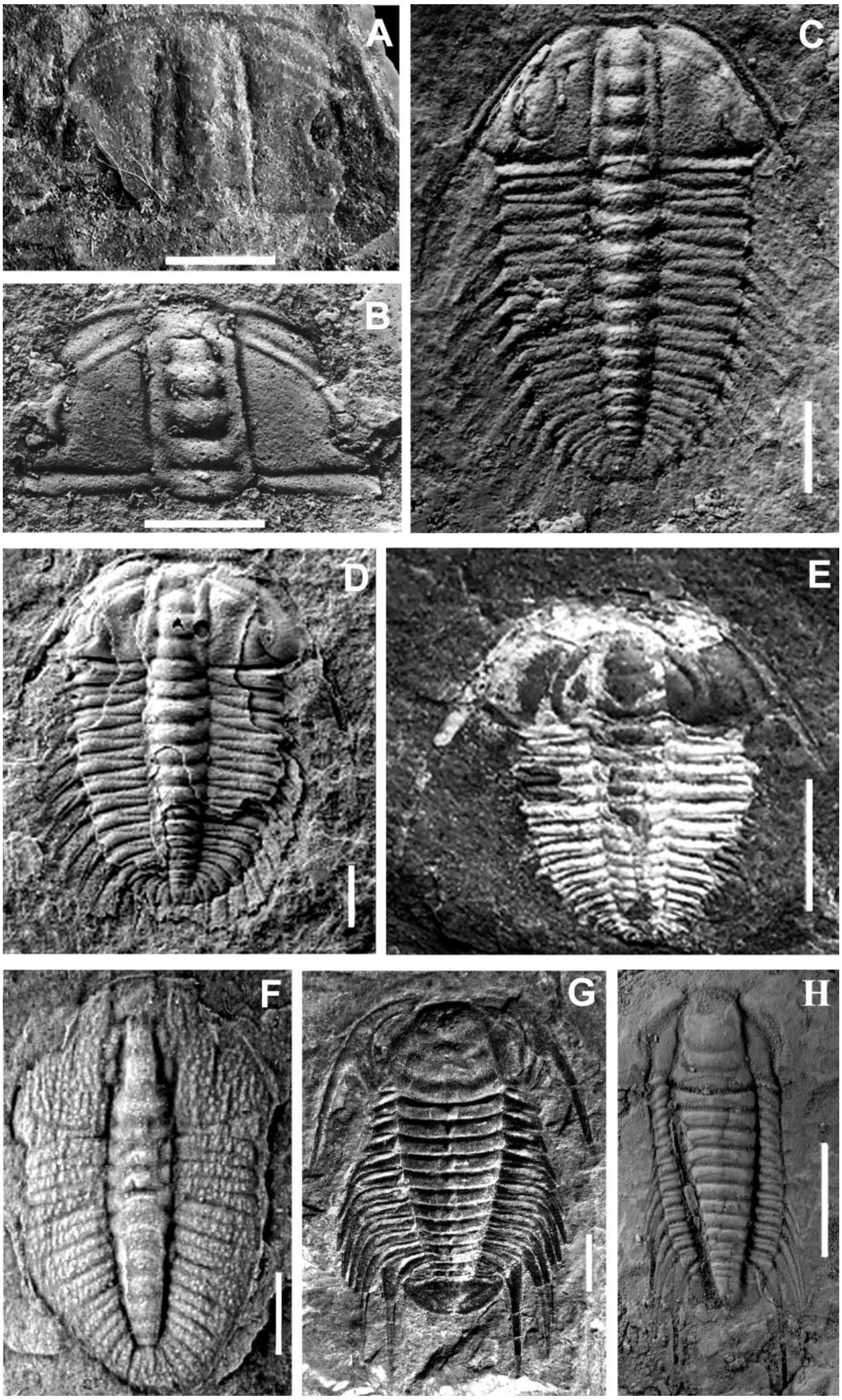

Fig. 8. Key trilobite species used for recognition of the base of the proposed Miaolingian Series and Wuliuan Stage. All specimens were collected from the Kaili Formation of the Wuliu-Zengjiayan section. A–D, *Oryctocephalus indicus* (Reed, 1910). A, cranidium, GTBB1-15-19a, 52.8 m (first appearance 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. GTBB1-3-3, exoskeleton, 49.4 m; F, *Ovatoryctocara sinensis* Zhao et al., 2015. 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.

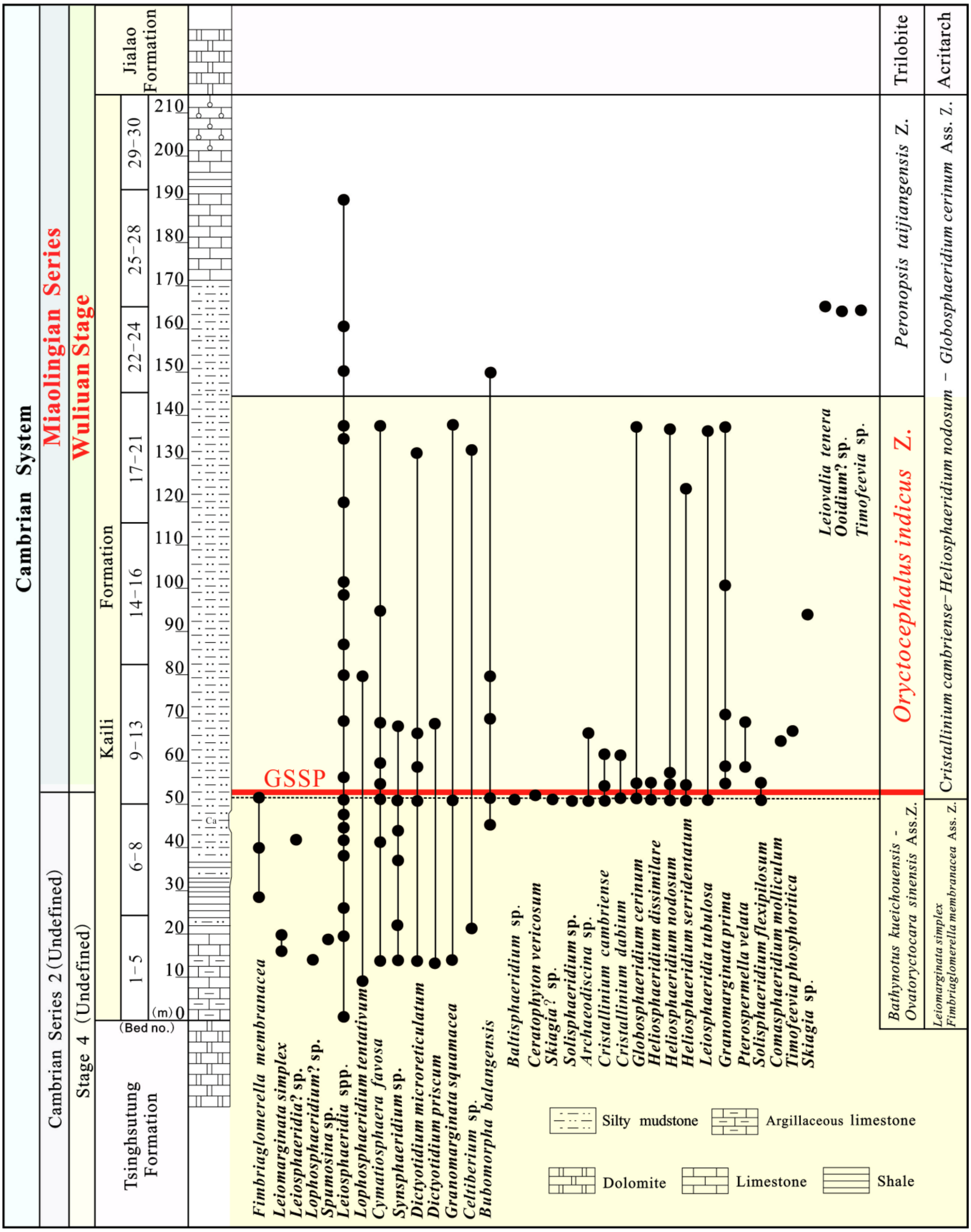

Fig. 9. Observed stratigraphic distribution of acritarchs in the Kaili Formation around the base of the *Oryctocephalus indicus* Zone (modified from Yin et al., 2010) in the Wuliu-Zengjiayan section.

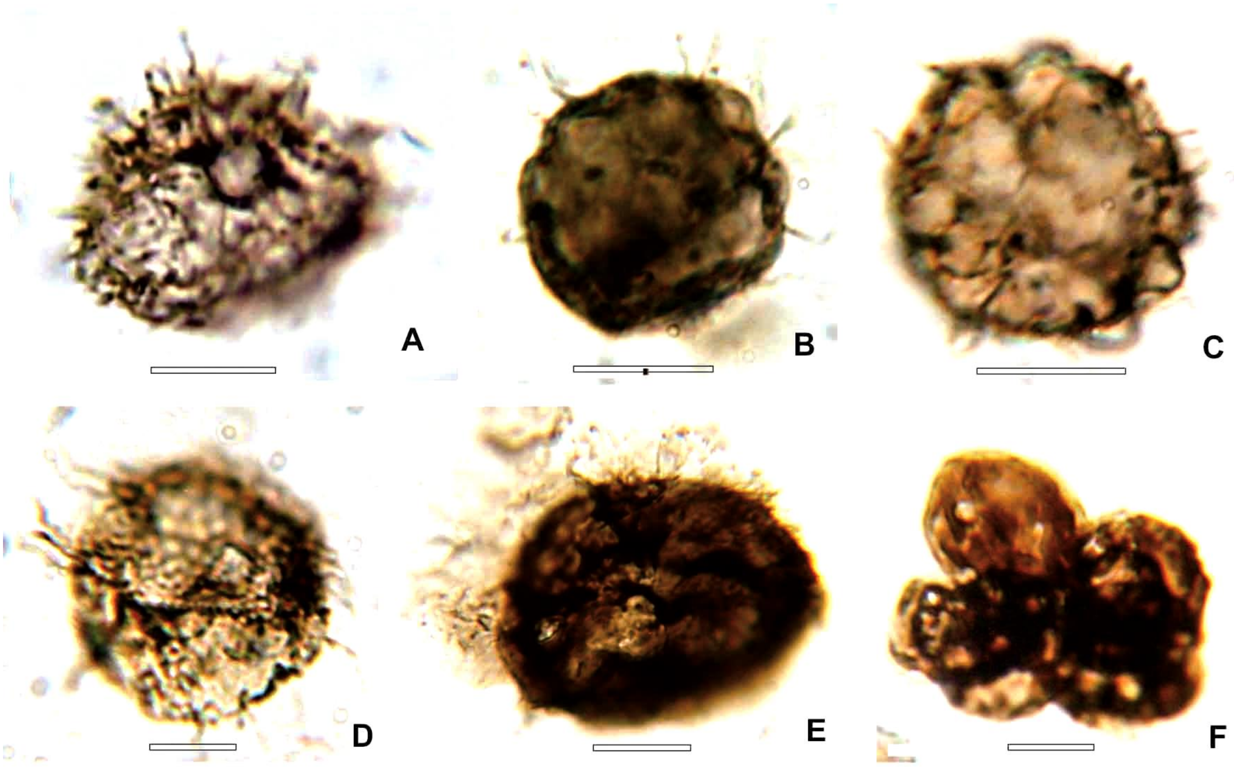

Fig. 10. Acritarchs from the Kaili Formation of the Wuliu-Zengjiayan section, Jianhe, Guizhou. A. *Heliosphaeridium nodosum* Moczydłowska, 1998, sample No.: FZX25; B, C. *Globosphaeridium cerinum* (Volkova) comb. Moczydłowska, 1991, sample No.: FZX25 (b), FZX24(c); D. *Solisphaeridium flexipilosum* (Slavicova) comb. Moczydłowska, 1998, sample No.: FZX26; E. *Comasphaeridium molliculum* Moczydłowska and Vidal, 1988, sample No.: K69; F. *Synsphaeridium* sp. sample No.: K51. All scale bars equal 10 µm.

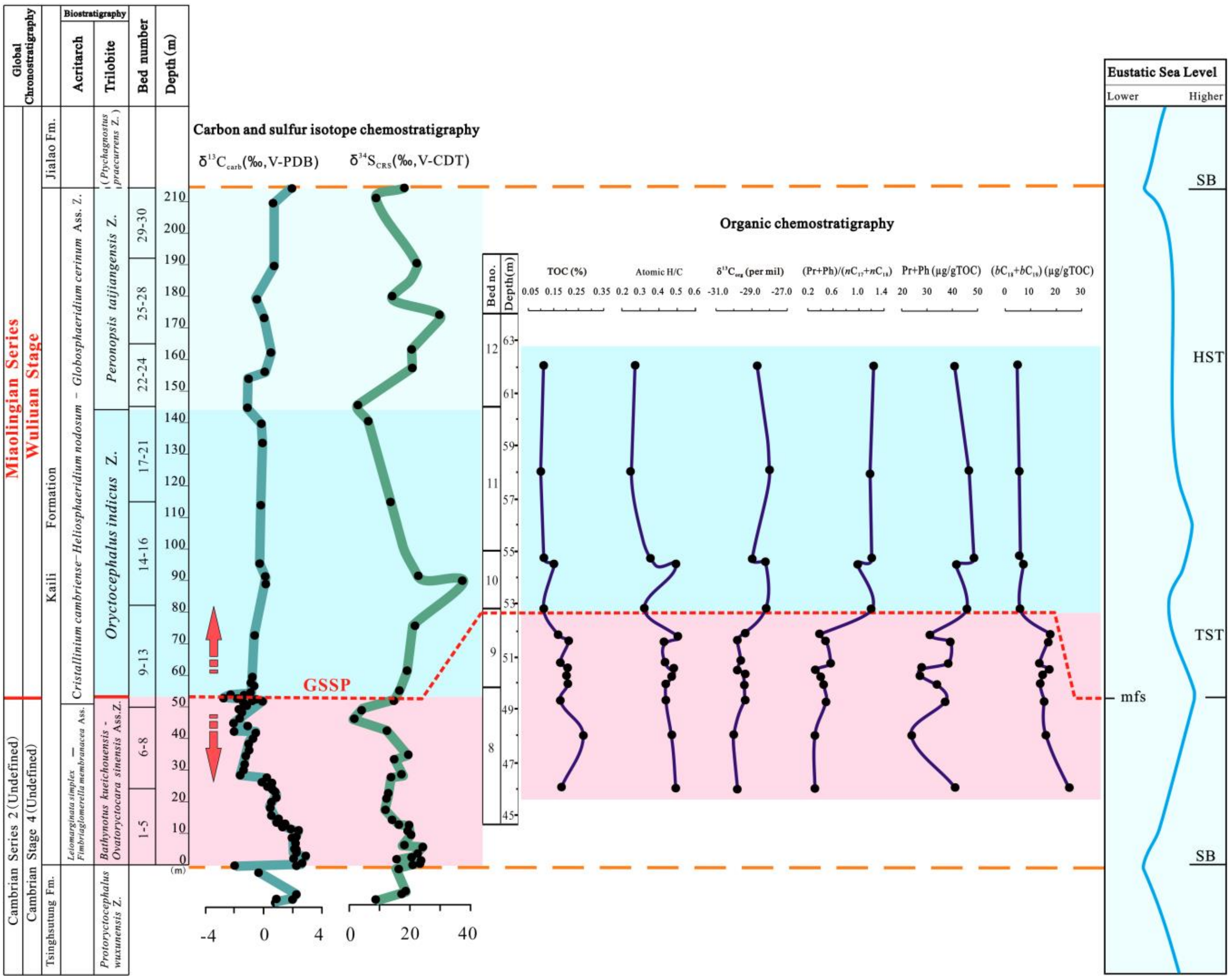

Fig. 11. Summary of primary and secondary stratigraphic indicators for the base of the proposed Miaolingian Series and Wuliuan Stage of the Cambrian System. Major stratigraphic tools used to constrain the GSSP of the proposed series and stage are trilobite biostratigraphy (Zhao et al., 2007, 2012, 2015), 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 (Wang et al., 2006; Gains et al., 2011). Notes: TOC for total organic carbon content in rocks; atomic H/C for atomic hydrogen/carbon ratio; $\delta^{13}C_{org}$ 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} for C_{18} and C_{19} midchain monomethyl branched alkanes, respectively, based on m/z 126+140+154+168+ 196+210+224 mass chromatograms.

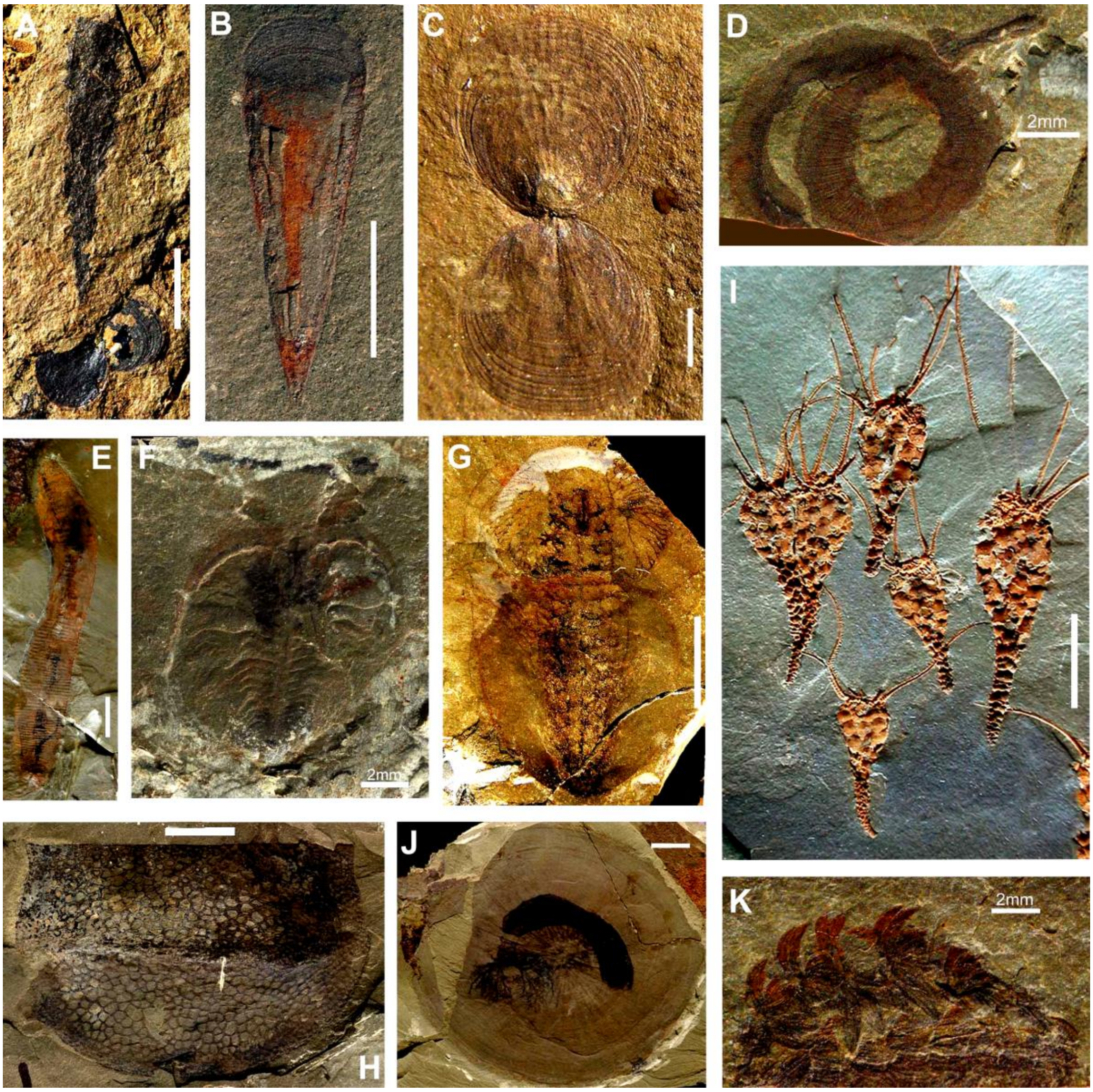

Fig. 12. Some metazoan taxa from the exceptionally preserved Kaili Biota in Balang Area, Jianhe, Guizhou. A, *Angulosuspongia sinensis* Yang et al., 2017 attached to *Glyptacrothele bohemica*, GTBM-9-2-1971; B, *Haplophrentis* cf. *carinatus* Matthew, 1899, GTBM-9-3162; C, *Acrothele* sp. GTBM-9-5365; D, Palaeoscolecid, gen. et sp. uncertain, GTBM-9-1b; E, *Ottoia guizhouensis* Yang et al., 2016, GTBM-9-4166; F, *Marrella* sp., ventral view, GTBM-9-5-1075; G, *Naraoia* cf. *compacta* Walcott, 1912, showing thin vessels in cephalic area; GTBM-9-3-5098; H, *Tuzoia bispinosa* Yuan et Zhao 1999,GM 9-5-1248; I, *Sinoeocrinus lui* Zhao et al, 1994, GTB-9-5-3495; J, *Pararotadiscus guizhouensis* Zhao and Zhu; 1994 emend.2002,GTBJ-13-3-220; K, *Wiwaxia taijiangensis* Zhao et al., 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.