Chinese Science Bulletin

Springer

The newly-developed Cambrian biostratigraphic succession and chronostratigraphic scheme for South China

PENG ShanChi

State Key Laboratory of Paleobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

Biostratigraphy and chronostratigraphy are common means of subdividing rock strata. The biostratigraphic succession and chronostratigraphic scheme are regarded as the basis for the subdivision and correlation of regional and global stratigraphic units. This paper reviews research on the biostratigraphy and chronostratigraphy carried out in the Jiangnan Slope Belt, South China since 1978, and, in particular, the biostratigraphic succession and chronostratigraphic scheme developed in the last decade. The updated biostratigraphic succession of South China includes 36 biozones, the base of each of which is defined by the first appearance of a single taxon (index fossil), and a poorly fossiliferous interzone. The updated chronostratigraphic scheme of South China comprises 4 series and 10 stages, embracing 3 global chronostratigraphic units, the Guzhangian Stage, Furongian Series, and Paibian Stage, and 2 GSSPs, all of which are erected in northwestern Hunan and 2 International Tie Points recognized in sections also in northwestern Hunan and each was accepted by the International Subcommission on Cambrian Stratigraphy for defining the base of the global stage. The biostratigraphic and chronostratigraphic systems are recognized as Chinese standards both domestically and worldwide. Future research is suggested for improving the two sets of stratigraphic standards.

Cambrian, trilobites, biostratigraphy, chronostratigraphy, slope belt facies, South China

In the authoritative book in stratigraphy "A Geologic Time Scale 2004" edited by Gradstein, the then Chairman of International Commission on Stratigraphy and others, the Cambrian chronostratigraphy of platform facies strata from North China and eastern Yunnan was no longer adopted in the updated Cambrian correlation charts as the Chinese standard, in contrast to all previous editions. They instead chose the chronostratigraphy and biostratigraphy based on the slope facies strata from the South China[1]. The new changes indicate that the newly developed biostratigraphic succession and chronostratigraphic scheme for South China have now been recognized worldwide.

Biostratigraphy and chronostratigraphy are important tools used commonly to establish relative geologic time relations and ages based respectively on the fossil contents and the time surfaces within the strata. In particular, the most diagnostic and widespread fossil taxa are used as index fossils for both subdividing the strata and establishing spatial and temporal correlations in the regional and international scales. As regional criteria, the detailed biostratigraphic succession and chronostratigraphical scheme erected on the sound study of taxonomy have fundamental significance in both science and geological practice. The Cambrian biostratigraphic succession and chronostratigraphy scheme of China have

Received June 25, 2009; accepted September 2, 2009
doi: 10.1007/s11434-009-0667-4
†Corresponding author (email: scpeng@nigpas.ac.cn)
Supported by the Key-Direction Project of Knowledge Innovation Program, Chinese Academy of Sciences (Grant No. KZCX2-YW-122), National Basic Research Program of China (Grant No. 2006CB806400, 2006FY120300), and National Natural Science Foundation of China (Grant Nos. 40023002 and 400332018)

Citation: Peng S C. The newly-developed Cambrian biostratigraphic succession and chronostratigraphic scheme for South China. Chinese Sci Bull, 2009, 54: 4161–4170, doi: 10.1007/s11434-009-0667-4

been traditionally defined based on the trilobite assemblages of the platform strata from the North China and eastern Yunnan[2–4]. These Cambrian trilobites have historical importance because North China and eastern Yunnan trilobites collectively have been studied for more than one hundred years[5,6]. Trilobites are the key group of fossils in the Cambrian; thus, they are the best candidates for subdividing and correlating Cambrian strata. However, trilobites found in the platform facies are mainly benthic polymerids with a restricted geographic distribution. Biostratigraphy and chronostratigraphy based on trilobites of platform facies have limited practical use in global correlation due to the endemism of these trilobites. In addition to the endemism of the chosen trilobite taxa, our traditional Cambrian biostratigraphic and chronostratigraphic units have other problems. For instance, the biozonation was defined at the genus-level, not at the species-level in the current standards; the chronostratigraphic unites were converted directly from lithostratigraphic units and were defined by unit stereotypes rather than the boundary stratotypes, and thus there were unavoidable overlaps or gaps in time in between successive chronostratigraphic units[7,8]. Furthermore, these Cambrian bio- and chronostratigraphic units are not useful for correlating strata between North and South China. The shortcomings of traditional Chinese Cambrian units made it difficult for these to be considered as global standards, especially after the development of new chronostratigraphic concepts based on GSSP—Global Standard Stratotype-section and Point in the 1970s. Therefore, it is necessary to establish a new Chinese Cambrian biostratigraphy and chronostratigraphy that match the modern concepts of the Cambrian stratigraphic units, and to strive for global standards.

The Jiangnan Slope Belt is located in the southeastern side of the Yangtze Platform during the Cambrian, and it is interpreted to be deposited in a deeper water setting[9]. The trilobite fauna is typical of this setting, containing abundant cosmopolitan agnostid trilobites and many widespread polymerid trilobites. Unlike endemic species used for traditional Chinese Cambrian biostratigraphy, these trilobites have wide geographic distributions; rapid evolutionary developments with relatively short stratigraphic ranges; and the fossil-bearing strata in the slope belt often are continuous with simple lithologies without major tectonic distortion. Therefore, the pandemic species in the slope belt have better potential for making regional and global correlations and defining biostratigraphic and chronostratigraphic standards. The modern history of studying Chinese Cambrian trilobites of the slope facies can be traced back to 1954, when Lu described six trilobite species from Sandu, eastern Guizhou[10]. There have been many more studies on the systematics and biostratigraphy of slope facies trilobites since, especially during the most recent 30 years. To date, there are 425 trilobite genera and more than 1000 species described from the Jiangnan Slope Belt[11–18]. In addition, important progress has been made on pre-trilobite Cambrian strata via the study of small shelly fossils (SSF) in the recent years[19,20]. These studies have provided invaluable information and a solid basis for establishing a new Cambrian biostratigraphy and chronostratigraphy in South China.

The first set of the new Cambrian biostratigraphic succession and chronostratigraphic scheme of South China was reported in 2000[21]. Recently, Peng[22] revised the Cambrian chronostratigraphy of South China. This study aims to provide updated information on the Cambrian biostratigraphy of South China.

1 The revised Cambrian biostratigraphic succession of South China

Studies of Cambrian biostratigraphy of Jiangnan Slope Belt began in the late 1970s. Yang[11] studied the traditional middle-upper Cambrian trilobite faunas in the contiguous areas between western Hunan and eastern Guizhou and he established six biozones based on polymeroid trilobites. Although Egorova et al.[23] conducted trilobite study in the same interval of the same areas as Yang did fifteen years earlier, they failed to recognize any trilobite zonation. Both Ergorova et al. and Yang described rich agnostoid trilobites and their findings provided valuable clues for making a detailed study of this important group of trilobites in the Jiangnan Slope Belt. In 1980, Zhou et al.[23] established five biozones in the traditional Lower Cambrian based on polymeroid trilobites from eastern Guizhou areas. Combining with studies in western Hunan and eastern Guizhou, polymerid trilobite biozones from the early Cambrian to early late Cambrian can be established. This succession, however, failed to use agnostoids having important stratigraphic applications, and remained the mid-upper part of the traditional Upper Cambrian undivided because the Jiangnan Slope Belt migrated seaward (to the

east) gradually[9] during the Cambrian. As a result of the migration, the depositional environments of western Hunan and eastern Guizhou areas became restricted shallow-water platform settings during the late Cambrian, in where, the main lithofacies are fossil-poor dolostones, lacking suitable trilobites for establishing biostratigraphic units. The regional surveys carried out in the 1970s and 1980s indicate that northwestern Hunan holds better geologic conditions than the contiguous areas between western Hunan and eastern Guizhou as it on the whole had maintained a slope environment during the Cambrian Period and received relatively complete carbonate succession with abundant trilobites including richer agnostoids than those from western Hunan and eastern Guizhou. Thus, study of slope facies trilobites had centered within northwestern Hunan and more and more results on the trilobite faunas of slope facies were published since 1987[13,14,16,25,26]. Based on detailed studies on the systematics of agnostid trilobites from five sections in northwestern Hunan at Shenjiawan in Cili, Waergang in Taoyuan, Paibi in Huayuan, Wangcun in Yongshun, and Luoyixi in Guzhang, Peng et al. developed basically an agnostoid trilobite-based biostratigraphic succession ranging from the Wulingian to the Furongian Series (traditional middle to upper Cambrian)[13,15,27]. Combing with other studies on the early Cambrian trilobite faunas and SSF in eastern Guizhou and Yunnan[19,24], Peng et al.[27] proposed the new Cambrian biostratigraphic succession in South China, containing 29 biozones in 2000. Based on more recent studies[17,20,28−31], this studied has modified the standard biozones from 29 to 37. They are listed as the following:

(37) *Hysterolenus* Zone (lower part)
(36) *Leiostegium constrictum-Shenjiawania brevis* Zone
(35) *Mictosaukia striata-Fatocephalus* Zone
(34) *Leiagnostus* cf. *bexelli-Archaeuloma taoyuanense* Zone
(33) *Lotagnostus americanus* Zone
(32) *Probinacunaspis nasalis-Peichiashania hunanensis* Zone
(31) *Eolotagnostus decorus-Kaolishaniella* Zone
(30) *Rhaptagnostus ciliensis-Onchonotellus* cf. *kuruktagensis* Zone
(29) *Agnostotes orientalis* Zone
(28) *Tomagnostella orientalis-Corynexochus plumula* Zone
(26) *Glyptagnostus reticulatus* Zone
(27) *Agnostus inexpextans-Proceratopyge protracta* Zone
(25) *Glyptagnostus stolidotus* Zone
(24) *Linguagnostus reconditus* Zone
(23) *Proagnostus bulbus* Zone
(22) *Lejopyge laevigata* Zone
(21) *Lejopyge armata* Zone
(20) *Goniagnostus nathorsti* Zone
(19) *Ptychagnostus punctuosus* Zone
(18) *Ptychagnostus atavus* Zone
(17) *Ptychagnostus gibbus* Zone
(16) *Peronopsis taijiangensis* Zone
(15) *Oryctocephalus indicus* Zone
(14) *Ovatoryctocara granulata-Bathynotus holopygus* Zone
(13) *Protoryctocephalus wuxunensis* Zone
(12) *Arthricocephalites taijiangensis* Zone
(11) *Arthricocephalus chauveaui* Zone
(10) *Arthricocephalus jiangkouensis* Zone
(9) Szechuanolenus-*Paokannia* Zone
(8) *Ushbaspis* Zone
(7) *Hupeidiscus-Sinodiscus* Zone
(6) *Tsunyidiscus niutitangensis* Zone
(5) *Sinosachites flabelliformis-Tannuolina zhangwentangi* Zone
(4) Poorly fossiliferous interzone
(3) *Watsonella crosbyi* Zone
(2) *Paragloborilus subglobosus-Purella squamulosa* Zone
(1) *Anabarites trisulcatus-Protohertzina anabarica* Zone

According to the standard Cambrian chronostratigraphy established in South China, the first five biozones belong to the Diandongian Series; nos. 6−14 biozones belong to the Qiandongian Series; nos. 15−25 biozones belong to the Wulingian Series; and nos. 26−37 biozones belong to the Furongian Series. Compared with the chart published in 2000 the new biostratigraphic succession has the following revisions:

(i) Based on suggestions proposed in Steiner et al.[20], the number of biozones in the Diandongian Series has been changed from previous 3 genus-level to 4 species-level assemblage biozones and one poorly fossiliferous interzone. The author agrees with them on the usages of both concurrent ranges of index species to recognize all the 4 biozones and the first appearance datum (FAD) of single taxon for defining the base of biozones nos. 3 and 4, but disagrees with them on the usage of FADs of two taxa for defining the base of the biozones nos.1 and 2. In order to avoid confusion caused by dual criteria, the usage of FAD of single taxon is suggested. Therefore, it is proposed here to use the FAD of *P. anabarica*, *P. subglobosus*, *W. crosbyi* and *T. zhangwentangi* for defining the basal boundaries of the biozones 1 to 4 in the Diandongian Series.

(ii) Biozonation in the Qiandongian Series has been changed from 6 genus-level assemblage biozones to 8 trilobite biozones following the FAD concepts. Among them six biozones are in species-level, of which the *T. niutitangensis* biozone corresponds to the basal part of the former *Hupeidiscus-Sinodiscus* biozone and the eponymous species has a lower occurrence than both of the former eponymous genera. *T. niutitangensis* has been

found widely in South China, and the biozonecan be recognized in many sections elsewhere. One of the new zone is the *Ushbaspis* biozone. It was modified from the *Metaredlichioides* [= *Ushbaspis*] – *Chengkouia* biozone in Zhou et al.[24] because *Ushbaspis* has relatively narrow stratigraphic occurrences in between *Hupeidiscus*- and *Szechuanolenus*-bearing strata in the sections such as at Meitan, Yuqing, Danzhai in eastern Guizhou. In addition, *Ushbaspis* has a wide geographic distribution. Except for eastern Guizhou, it is known also from eastern Sichuan and western Hubei in South China, and found at Wushi, western Xinjiang and Malyi Karatau, southern Kazakhstan[32−35]; thus, it is a good index fossil for intercontinental correlation. Due to the recent studies on the trilobite faunas from the Kaili Biota[17,31], the biozones nos. 10 to14 are revised from genus-level to species-level. The biozones nos. 10 to 15 are based on widespread orytocephalid trilobites. In particular, *A. chauveaui* and *O. granulata* are cosmopolitan species with good correlation utilities. Recently Yao et al.[36] erected an agnostoid biozone, the *Peronopsis taijiangensis* biozone, in the Kaili Formation, eastern Guizhou, which replaces the former *Arthricocephalus orientalis* Zone. In South China, *P. taijiangensis* has wider distribution than *A. orientalis* and the zone can be correlated with the earliest agnostoid zones globally; for instance, the *Peronopsis bonnerensis* Zone of Laurentia and the *Pentagnostus anabarensis* Zone of Australia.

(iii) A new *L. armata* biozone is added to the Wulingian Series based on the study of the Guzhangian GSSP at the Luoyixi section, Guzhang, northwestern Hunan[29]. *L. armata* is a cosmopolitan agnostoid species and is used as index fossil of eponymous zone in western Zhejiang, Tarim and southern Kazakhstan[15,37,38]. In the Cambrian sections in western Hunan, western Zhejinag, Tasmania and southern Kazakhstan, the FAD of the species is older than that of *L. laevigata* [16,29,38,39].

(iv) Revisions of trilobite systematics[16,40] allow us to interpret *Innitagnostus inexpectans*, *Agnostotes clavata* and *Lotagnostus punctuosus* here as junior synonyms of *Agnostus inexpectans*, *Agnostotes orientalis* and *Lotagnostus americanus* and to revise their eponymous zones.

(v) *T. orientalis*-*C. plumula* biozone is based on the interval occupied by the agnostid trilobite biozone *T. orientalis* and the polymeroid trilobite biozone *C. plumula* in the Duibuian B section, western Zhejiang[30]. Although the stratigraphic ranges of the two species are approximately the same, the FAD of *T. orientalis* is slightly older; thus, it is used for defining this biozone. The new biozone replaces the previously defined *C. plumula*-*S.* cf. *kiangshanensis* biozone, but the intervals of the new and replaced biozones are about the same based on the ranges of both *C. plumula* and *S. kiangshanensis* in the Duibian B section and FAD of *Irvingella angustilimbata* in the sections of northwetsren Hunan and western Zhejiang. *Agnostotes orientalis* and *Lotagnostus americanus* biozones are also recognized in the the Duibian B section, replacing respectively the former *Agnosrotes orientalis*-*Irvingella angustilimbata* and *L. americanus*-*Hedinaspis regarlis* biozones. The lower boundary of each zone is defined by the "international tie point" [30], and the FAD of *L. americanus*, based on the detailed study of specific ranges, is much earlier than that of *Hedinaspis regarlis* in the section[30].

(vi) The global Cambrian-Ordovician boundary is defined based on the FAD of the conodont *Iapetognathus fluctivagus*[41]. In the Waergang section, Taoyuan, South China, *I. fluctivagus* occurs in the middle of *Cordylodus lindstromi* conodont biozone. In Tarim, *C. lindstromi* occurs in the upper part of the *Hysterolenus* trilobite biozone[42]. Therefore, the lower and middle part of the *Hysterolenus* trilobite biozone, which was previously regarded to be Ordovician in age, should be included in the Cambrian, and the *Hysterolenus* biozone (in part) is added as the youngest Cambrian trilobite biozone in South China.

The new Cambrian biostratigraphic succession of South China is distinct and has proved to be advantageous in stratigraphic subdivision and correlation. Firstly, all the biozones in succession are well defined. It is essentially distinct from any traditional biostratigraphic zonation established in the past in China as regional and national standard. Every biozone in the succession of South China is an interzone defined between the lowest occurrences of two specified taxa, i.e. the base of each biozone is defined by the FAD of a single taxon, whereas previous zonantions are either based on concurrent range zone or acme zone. The new zonation of South China possesses chronostratigraphic attribute, and the zonal boundary can be used as chronostratigraphic boundary because the FAD of a fossil taxon implies a "time surface".

Secondly, the most of biozones in the South China succession are correlatable over long-distances. For instances, here are 17 out of 23 trilobite biozones in the Wulingian Series and Furongian Series based on the

FAD of cosmopolitan agnostid trilobites. Among them, nos. 15—24 agnostid biozones are considered by colleagues as the international standards[43,44]; the FADs of *L. laevigata* and *G. reticulatus* are stratotype points defining the bases of Paibian Stage and Guzhangian Stage respectively in the global Cambrian System; the index fossils *A. orientalis* and *L. americanus* are voted by the members of the International Subcommission on Cambrian Straitgraphy (ISCS) as the key species for defining the global Cambrian Stage 9 and 10 respectively[45]. Besides, the *A. trisulcatus-P. anabarica* biozone and *W. crosbyi* biozone in the Diandongian Series and the *A. chauveaui* biozone and *O. granulata-B. holopygus* biozone in the Qiandongian Series contain cosmopolitan species with good correlation utilities[20,31,46,]. At the present stage, the biostratigraphic succession of South China is one of the best Cambrian standards for international correlation.

Thirdly, the Cambrian slope facies trilobite faunas from South China comprise various trilobites known also in the faunas from North China and Tarim. This feature is conducive to solving the long-standing correlation difficulties among South China, North China and Tarim blocks. Based on the recent statistics[47], 28% of the trilobite fauna genera of North China are found in the Jiangnan Slope Belt of South China. Important shared taxa include *Palaeolenus, Redlichia, Amphoton, Dorypyge, Fuchouia, Changqingia, Damesella, Parablackwelderia, Blackwelderia, Chuangia, Prochuangia, Peichiashania, Maladioidella, Kaolishaniella, Irvingella, Tsinania, Prosuakia, Saukia, Mictosuakia, Fatocephalus,* and *Leiostegium* in the Wulingian Series and Furongian Series. On the other hand, the overall trilobite assemblage in the Tarim is more similar to that in the South China than that in the North China with most of its biozones sharing the same zonal names with those of South China. The biozones with different names in both blocks are also easily correlatable. For instance, the eponymous species of the *Pseudophalacroma ovale* biozone of Tarim is restricted in the *Goniagnostus nathorsti* biozone in South China, and appears firstly together with *G. nathorsti*[16]. Therefore, the base of *P. ovale* biozone coincides with that of *G. nathorsti* biozone completely. The base of the *Lejopyge armata* biozene in Tarim is correlabtable with that of the *L. armata* biozone in South Chin, and, except for appearing slightly earlier, *L. armata* overlaps most of its range with *Lejopyge laevigata*. In addition, the overlying *Proagnostus bulbus* biozone in South China contains a number of important taxa including *Proagnostus* [=*Agnostascus* sp.], *Lejopyge sinensis, Goniagnostus fumicola, Oidalagnostus trispinus* [=*O. tienshanensis*], which are only restricted to *Lejopyge sinensis* biozone in the Tarim[16, 37]. Therefore, *L. armata* biozone of Tarim correpands actually the *L. laevigata* biozone of South China, and the *Lejopyge sinensis* is completely correlatble with the *P. bulbus* biozone of South China.

The updated correlation of Cambrian strata from the South China, North China and Tarim blocks is summarized in Table 1. In particular, the correlation to the North China is based on the new studies of polymerid trilobites from the Jiangnan Slope Belt[17,18] and southern part of the Northeast China[48].

2 The new Cambrian chronostratigraphic scheme of South China

Compared to the first Chinese Cambrian chronostratigraphy proposed by Sun (1961) on the basis of North China's formations the study on the Cambrian chronostratigraphy of South China had not got started until 37 years later. However, new chronostratigraphic concepts were developed during this time period. In particular, International Commission on Stratigraphy (ICS) began to use index fossils that have global correlation utility in a continuous sedimentary succession, known as the concept of GSSP, to define chronostratigraphic units[7,49,50]. On the other hand, the International Subcommission on Cambrian Stratigraphy (ISCS) started out to solve the problems relating to the subdivision of the global Cambrian System[51]. Therefore, the modern study of Cambrian chronostratigraphy of South China is able to follow the new chronostratigraphic concepts and international standards, integrating with the ISCS goals. In 1998 at the ISCS meeting held in Lund, Sweden, Peng et al.[52] pointed out the necessity of establishing the Cambrian chronostratigraphy of South China by replacing the traditional North China scheme because the latter is defined by the endemic trilobite species and is actually lithostratigraphic than chronostratigraphic in concept. They proposed four new stages, the " Wangcunian Stage", "Youshuian Stage", "Waergangian Stage" and "Taoyuanian Stage" as the chronostratigraphic units of South China with the FADs of *Ptychagnostus punctuosus, Linguagnostus recondius, Glyptagnostus reticulatus* and *Agnostotes americanus* [= *A. clavatus*] at the

Table 1 Biostratigraphic correlation among South China, Noth China and Tarim Blocks

Series	Stage	South China (This paper)	North China[47,48]	Tarim[37,42]
Furongian	Niucheheam	*Hysterolenus* (lower part)	*Yosimuraspis* (lower part)	*Hysterolenus* (lower part)
		Leiostegium constrictum-Shenjiawania brevis	*Pseudokoldinioidia perpeltis*	*Lotagnostus hedini*
		Mictosaukia striata-Fatocephalus	*Mictosaukia*	
		Leiagnostus cf. *bexilli-Archaeuloma taoyuanense*	*Changia*	*Lotagnostus americanus-Hedinaspis*
		Lotagnostus americanus		
	Taoyuanian	*Probinacunaspis nasalis-Peichiashania hunanensis*	*Tsinania-Ptychaspis*	*Irvingella-Sinoproceratopyge kiangshanensis*
		Eolotagnostus decorus-Kaolishaniella	*Kaolishania*	
		Rhaptagnostus ciliensis-Oncholotellus cf. *kuruktagensis*	*Maladioidella*	
		Agnostotes orientalis	*Changshania*	
	Paibian	*Tomagnostella orientalis-Corynexochus plumula*	*Chuangia*	
		Agnostus inexpextans-Proceratopyge protracta		*Glyptagnostus reticulatus/Prochuangia*
		Glyptagnostus reticulatus		
Wulingian	Guzhangian	*Glyptagnostus stolidotus*	*Prochuangia-Paracoosia*	*Glyptagnostus stolidotus*
		Linguagnostus reconditus	*Neodrepanura*	*Buttsia-Acmarhachis*
		Proagnostus bulbus	*Blackwelderia*	*Lejopyge sinensis*
		Lejopyge laevigata		*Lejopyge armata*
	Wangcunian	*Lejopyge armata*	*Damesella-Yabeia*	
		Goniagnostus nathorsti	*Liopeishania*	*Pseudophalacroma ovale*
		Ptychagnostus punctuosus	*Taitzuia-Poshania*	*Ptychagnostus punctuosus*
	Taijiangian	*Ptychagnostus atavus*	*Amphoton*	*Ptychagnostus atavus*
		Ptychagnostus gibbus	*Crepicephalina*	(no zonation)
		Peronopsis taijiangensis	*Bailiella-Lioparia*	
		Oryctocephalus indicus	*Poriagraulos*	
Qiandongian	Duyunian	*Ovatoryctocara granulata-Bathynotus holopygus*	*Inouyops*	
		Protoryctocephalus wuxunensis	*Metagraulos*	
		Arthricocephalites taijiangensis	*Sunaspis-Sunaspidella*	
		Arthricocephalus chauveaui	*Sinopagetia jinnanensis*	
	Nangaoan	*Arthricocephalus jiangkouensis*	*Ruichengaspis*	
		Szechuanolenus-Paokannia	*Hsuchuangia-Ruichengella*	
		Ushbaspis	*Shantungaspis*	
		Hupeidiscus-Sinodiscus	*Yaojiayuella*	
		Tsunyidiscusniutitangensis	*Qiaotouaspis*	*Arthricocephalus-Changsapis*
Diandongian	Meishucunian	*Sinosachites flabelliformis-Tannuolina zhangwentangi*	*Redlichia nobilis*	
		poorly fossiliferous interzone	*Redlichia* (*Pteroredlichia*) *chinensis*	
		Watsonella crosbyi	*Palaeolenus* [=*Megapalaeolenus*]	
		Paragloborilus subglobosus-Purella squamulosa		*Tianshanocephalus*
	Jinningian	*Anabarites trisulcatus-Protohertzina anabarica*	(hiatus)	*Ushbaspis-Chengkouia*
		(barren interval)		(no zonation)

Wangcun and Waergang sections in northwestern Hunan to define the bases of these stage respectively. Afterward, a new Taijiangiang Stage is added and its base is defined by the FAD of *Oryctocephalus indicus* at the Balang section in Taijiang (now Jianhe) County, eastern Guizhou[53].

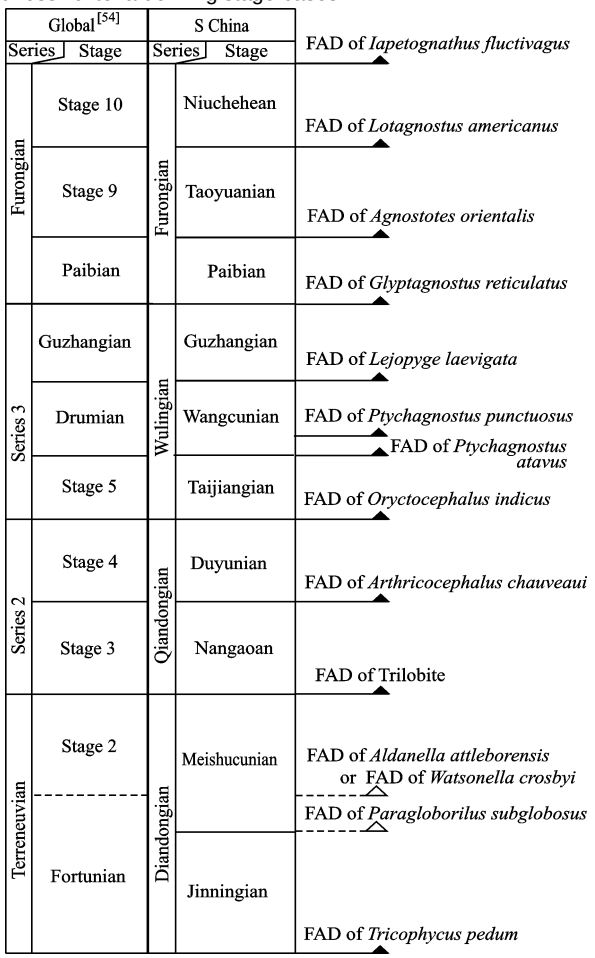
The entire Cambrian chronostratigraphic scheme of South China was proposed in 2000, consisting of 4 series and 9 stages. They are Jinningian Stage and Meishucunian Stage in the Diandongian Series, Nangaoan Stage and Duyunian Stage in the Qiandongian Series, Taijiangian Stage, Wangcunian Stage and Youshuian Stage in the Wulingian Series and Waergangian Stage and Taoyuanian Stage in the Hunanian Series. The new Cambrian scheme uses 4 series instead of traditional 3 series subdivision. This is because the base of traditional lower Cambrian has been pushed lower to incorporate a pre-trilobite interval in the past decades. As a result, the duration of "early Cambrian", to which approximately 20 Ma had been increased, is longer than the total duration of "middle and upper Cambrian". Therefore, it is logical to subdivide the "early Cambrian" into two series, including a pre-trilobite series, so that the interval occupied by the new Cambrian Series 2 to 4 is close to the concept of the Cambrian System without lowering its base. In addition, the basal boundaries of all new Cambrian stages are defined based on the boundary stratotypes and most of the selected index fossils defining the stage base employ the "International Tie Points", following the rules for establishing global chronostratigraphic units. As the boundary stratotypes of these stages meet the basic requirements to be considered as GSSP candidates, creating the opportunity for erecting GSSPs and global chronostratigraphic units in South China. Moreover, the Cambrian System of South China shares the same definition with the global Cambrian System as its lower boundary and the lower boundary of Ordovician (the top of Cambrian) are defined by the same criteria as those defining the bases of global Cambrian and Ordovician.

The chronostratigraphic study of South China has also encouraged our studies on establishing the global Cambrian chronostratigraphy and achieved significant results. For instance, the first intra-Cambrian GSSP was erected with the first appearance datum (FAD) of *Glyptagnostus reticulatus* at the Paibi section, Hunan, South China for defining the base of the global Paibian Stage and Furongian Series; an additional GSSP was erected with the FAD of *Lejopyge laevigata* at the Luoyixi Section, Hunan for defining the base of Guzhangian Stage; the FADs of the agnostid trilobites *Agnostotes orientalis* and *Lotagnostus americanus*, recognized in the sections in the Taoyuan-Cili areas, Hunan[40], have been chosen by ISCS vote as the key criteria for defining the bases of global Cambrian Stage 9 and 10 respectively[45]. All these achievements require a revision on the Cambrian chronostratigraphic scheme of South China by including the GSSPs and the International Tie Points. As revised[22], the new scheme with 4 series and 10 stages reflects the basic framework adopted for the global Cambrian chronostratigraphy. The new scheme replaces the Youshuian Stage and Waergangian Stage with the global Guzhangian Stage and Paibian Stage; replaces Hunanian Series with Furongian Series; and adds the Niuchehean Stage at the top of Furongian Series with its base defined by the FAD of *L. americanus*, an International Tie Point. In this study, the base of the Wangcunian Stage is moved downward in its boundary stratotype at Wangcun, Yongshun, Hunan, from the FAD of *Ptychagnostus punctuosus* to the FAD of *Ptychagnostus atavus*, i.e. a full zone, so that the revised base of the Wangcunian Stage is coincided with that of the global Drumian Stage. Except for the bases of the Meishucunian Stage, the stage bases in revised Cambrian chronostratigraphic scheme of South China coincide with those in the global Cambrian chronostratigraphic scheme (Table 2)

3 Conclusions and the outlook

The Jiangnan Slope Belt of the South China contains one of the most fossiliferous Cambrian strata with continuous sedimentary deposits and detailed and complete biostratigraphic succession in the world[54]. Its Cambrian biostratigraphy has been adopted by the ISCS and used in the official global Cambrian correlation chart[55] and accepted by the ICS as the Chinese Cambrian standard[1,54]; the chronostratigraphic scheme of South China has been also accepted by the ICS as Chinese standard[1,55]. The latter formed important bases for establishing the global Cambrian chronostratigraphic scheme adopted in the "International Stratigraphic Chart"[56]. The 2 GSSPs for the Paibian Stage and Guzhangian Stage and the 3 chronostratigraphic units the Furongian Series, Paibian Stage, and Guzhangian Stage, all of which are erected in South China, have been incorpo-

Table 2 Global and South China's chronostratigraphic subdivision and fossil criteria defining stage bases[a)]



a) The solid line arrow in the right column indicates International Tie Point (ITP) or GSSP; the doted line arrow indicates level to be recognized as ITP.

rated into the latest "International Stratigraphic Chart". Furthermore, the National Stratigraphy Commission of China has decided to adopt the Cambrian chronostratigraphic scheme of South China in the forthcoming edition of "Stratigraphic Chart of China"[1)]. Though the biostratigraphic and chronostratigraphic study of South China is proved to be one of the most significant achievements in stratigraphy in China since 1949 and have been recognized domestic and worldwide with receiving positive impact abroad, there are some future works needed in order to make the Cambrian biostratigraphic succession and chronostratigraphic scheme more improved: (1) the Balang section at Jianhe, eastern Guizhou and the Duibian section at Jiangshan, Zhejiang have GSSP potentials and they are candidate sections for the global Cambrian Stages 5 and 9 respectively. More detailed study on the boundary interval of both sections is required to strengthen their competitive edge. If they are chosen as GSSPs, then the Taijiangian Stage and Taoyuanian Stage of South China can be considered as global standard units. (2) Search for better sections for biostratigraphic study of the Nangaoan Stage in southeastern Guizhou to improve the *Hupeidiscus-Sino- discus* biozone, *Ushbaspis* biozone and *Szechuanolenus-Packannia* biozone to the species-level zones. (3) Occurrences of SSF are limited to the strata from the platform facies; thus, it is necessary to restudy the base of Meishucunian Stage in the northeastern Yuanan, combined with the study of the base of global stage 2, in order to coincide, as far as possible, the base of the Chinese stage with that of global stage 2 (The potential levels proposed buy Chinese and Russian experts[57−59] to define the base of the global Stage 2 are shown on the Table 2). (4) Search for better sections in the eastern Yuanan to fill the gap in the barren zone. (5) Increase the study of zircon dating from the ash layers in the South China to provide Chinese data of the absolute geologic age constrains for the Chinese chronostratigraphic scheme.

1 Shergold J, Cooper R A. Cambrian Period. In: Gradstein F, Ogg J, Smith A, eds. A Geologic Time Scale 2004. Cambridge: Cambridge University Press, 2004. 147−163

2 Sun Y Z. Subdivision of Chinese Cambrian System (in Chinese). Acta Geol Sin, 1961, 41: 285−289

3 Lu Y H. Cambrian System of China. In: Chinese Commission on Stratigraphy, ed. Collection of papers presented at the National Congress on Stratigraphy: Cambrian System of China (in Chinese). Beijing: Science Press, 1962. 1−117

4 Xiang L W, Li S J, Nan R S, et al. Stratigraphy of China (4), the Cambrian System of China (in Chinese). Beijing: Geological Publishing House, 1981

5 Dames W. Kambrische Trilobiten von Liaotung. In: Richthofen F F, ed. China, Ergebnisse eigner Reisen und darauf gegundete Studien, 4, Palaeontology (in German). Berlin: Dietrich Reimer, 1883. 3−33

6 Mansuy H. Étude géologique du Yunnan oriental, Part 2: Paléontologie (in French). Mémoires du Service Géologique de l'Indochine, 1912, 1: 1−146

7 Salvador A, ed. International Stratigraphic Guide—a Guide to Stratigraphic Classification, Terminology and Procedure. Bouder: IUGS & GSA, Inc., 1994

8 Peng S C, Zhou Z Y, Lin T R, et al. Cambrian chronostratigraphy

1) National Commission on Stratigraphy of China. Instructions for compiling "Stratigraphic Chart of China". 2008. 14

research: present and tendency (in Chinese). J Strat, 2000, 24: 8－17
9 Chen Z M. A discussion on geologic background for carbonate gravity flows in Early Paleozoic carbonate rocks on Yangtze Platform (in Chinese). Sci Geol Sin, 1991: 337－345
10 Lu Y H. Upper Cambrian trilobites from Santu, southeastern Kueichou (in Chinese and English). Acta Palaeont Sin, 1954, 2: 117－152
11 Yang J L. Middle and Upper Cambrian trilobites of western Hunan and eastern Guizhou. In: Editorial Committee of Stratigraphic and Palaeontological Papers, ed. Professional Papers of Stratigraphy and Palaeontology, 4 (in Chinese). Beijing: Geological Publishing House, 1978. 1－83
12 Peng S C. Cambrian-Ordovician boundary in the Cili-Taoyuan border area, northwestern Hunan with description of relate trilobites. In: Nanjing Institute of Geology and Palaeontology, Academia Sinica, ed. Stratigraphy and Palaeontology of Systemic Boundaries in China, Cambrian and Ordovician Boundary (1). Hefei: Anhui Science & Technology Publishing House, 1984. 285－405
13 Peng S C. Early Late Cambrian stratigraphy and trilobite fauna of Taoyuan and Cili, Hunan. In: Nanjing Institute of Geology & Palaeontology, Academia Sinica, ed. Collection of Postgraduate Theses, 1 (in Chinese). Nanjing: Jiangsu Science & Technology Publishing House, 1987. 53－134
14 Peng S C. Upper Cambrian Biostratigraphy and Trilobite Faunas of Cili-Taoyuan Area, Northwestern Hunan, China. Mem Association Australasian Palaeontologits, 1992, 13: 1－119
15 Lu Y H, Lin H L. The Cambrian Trilobites of Western Zhejiang (in Chinese). Palaeont Sin, n s B, 25 (175), Beijing: Science Press, 1989
16 Peng S C, Robison R A. Agnostoid biostratigraphy across the Middle-Upper Cambrian boundary in Hunan, China. J Paleont，2000, 74 (suppl): 1－104[doi]
17 Yuan J L, Zhao Y L, Li Y, et al. Trilobite Fauna of the Kaili Formation (Uppermost Lower Cambrian–Lower Middle Cambrian) from Southeastern Guizhou, South China (in Chinese). Shanghai: Shanghai Science and Technology Press, 2002
18 Peng S C, Babcock L E, Lin H L. Polymerid Trilobites From the Cambrian of Nothwestern Hunan, China, Volume 1, Corynexochida, Lichida, and Asaphida; Volume 2, Ptychopariida, Eodiscida, and Undetermined Forms. Beijing: Science Press, 2004
19 Luo H L, Jiang Z W, Tang L D. Stratotype Section for Lower Cambrian Stages in China (in Chinese). Kunming: Yunnan Science and Technology Press, 1994
20 Steiner M, Li G X, Qian Y, et al. Neoproterozoic to early Cambrian small shelly fossil assemblages and a revised biostratigraphic correlation of Yangtze Platform (China). Palaeogeogr. Palaeoclimat. Palaeoecol, 2007, 254: 67－69[doi]
21 Peng S C. Cambrian of slope facies. In: Nanjing Institute of Geology and Palaeontology, Academia Sinica (ed.), Stratigraphical Studies in China (1979－1999) (in Chinese). Hefei: Press of University of Science and Technology of China, 2000. 23－28
22 Peng S C. Revision on Cambrian chronostratigraphy of South China and related Remarks (in Chinese). J Strat, 2008, 32: 239－245
23 Egorova L I, Xiang L W, Li S J, et al. Cambrian trilobite faunas of Guizhou and western Hunan (in Chinese). Special Paper Inst Geol Min Resour, Ser B, Strat Palaeont, 1963, 3: 1－117
24 Zhou Z Y, Yuan J L, Zhang Z H, et al. Classification and correlation of Cambrian in Guizhou (in Chinese). J Strat, 1980, 4: 273－281
25 Lin T R. Middle Cambrian stratigraphy and trilobite fauna of Taoyuan, NW-Hunan (in Chinese). Acta Palaeont Sin, 1991, 30: 360－376
26 Dong X P. Late Middle and early Late Cambrian agnostids in Huayuan, Hunan. Acta Palaeont Sin, 1991, 30: 439－457
27 Peng S H. Upper Cambrian in the Cili-Taoyuan Area, Hunan and its trilobite succession (in Chinese). J Strat, 1990, 14: 261－276
28 Dong X P, Repetski J E, Bergtröm S M. Conodont biostratigraphy of the Middle Cambrian through lowermost Ordovician in Hunan, South China. Acta Geol Sin, 2004, 78: 1185－1260
29 Peng S C, Babcock L E, Zuo J X , et al. Proposed GSSP for the base of Cambrian Stage 7, coinciding with the first appearance of *Lejopyge laevigata*, Hunan, China, Palaeoworld, 2006, 15: 367－383[doi]
30 Peng S C, Babcock L E, Zuo J X, et al. Proposed GSSP for the base of Cambrian Stage 9, coinciding with the first appearance of *Agnostotes orientalis*, at Duibian, Zhejiang, China. Sci China Ser D-Earth Sci, 2009, 52: 434－451[doi]
31 Yuan J L, Zhao Y L, Peng J, et al. Cambrian trilobite *Ovatorycto-cara granulata* Tchernysheva, 1962 and its biostratigraphic significance. Prog Natur Sci, 2009, 19: 213－221[doi]
32 Zhang W T, Lu Y H, Zhu Z L, et al. Cambrian Trilobite Faunas of Southwestern China (in Chinese). Palaeont Sin, n s B, 16(159). Beijing: Science Press, 1980
33 Zhou T M, Lin T. Early Cambrian trilobite. In: Stratigraphic Research Group of Yangtze Gorges, Hubei Bureau of Geology, ed. Sinian to Permian Stratigraphy and Palaeontology of the Eastern Yangtze Gorges Area (in Chinese). Beijing: Geological Publishing House, 1978. 143－154
34 Zhang T R. Class Trilobita. In Regional Surveying Team of Xinjiang Bureau of Geology, Geological Institute of Xinjinag Bureau of Geoloy, Geological Surveying Branch of Xinjiang Bureau of Petroleum, eds. Palaeontological Atlas of Northwest China, Xinjiang, 1 (in Chinese). Beijing: Geological Publishing House, 1981. 134－213
35 Keller B M, Pokrovskaya N V. New information about the age of the phosphorites in Karatau (in Russian). Izvestiya Akademii Nauk SSSR, Ser Geol, 1965, 6: 78－79
36 Yao L, Peng J, Fu X P, et al. Ontogenesis of *Tuzoia bispinosa* (Arthripoda) from the Middle Cambrian Kaili biota, Guizhou, China. Acta Palaeont Sin, 2009, 48: 56－64
37 Lin H L, Chen T E, Yuan J L, et al. Cambrian. In: Zhou Z Y, ed. Stratigraphy of the Tarim Basin (in Chinese). Beijing: Science Press, 2001. 12－38
38 Ergaliev G Kh. Middle and Upper Cambrian Trilobites from Malyi Karatau (in Russian). Alma-Ata: Science Press of Kazakhstan SSR, 1980
39 Jago J B. Late Middle Cambrian agnostid trilobites from the Gunns Plains area, northwestern Tasmania. Pap Proceed Roy Soc Tasmania, 1976, 110: 1－18
40 Peng S C, Babcock L E. Two Cambrian agnostoid trilobites, *Agnostotes orientalis* (Kobayashi, 1935) and *Lotagnostus americanus* (Billings, 1860): key species for defining global stages of the Cambrian System, Geosci J, 2005, 9: 107－115[doi]
41 Cooper R A, Nowlan G S, Williams S H. Global Stratotype Section and Point for base of the Ordovician System. Episodes, 2001, 24: 19－28

42 Zhou Z Y, Chen X, Wang Z H, et al. Ordovician. In: Zhou Z Y, Chen P J, eds. Biostratigraphy and Geological Evolution of Tarim (in Chinese). Beijing: Science Press, 1990. 56－130
43 Weidner T R, Ahlberg P, Axheimer N, et al. The middle Cambrian *Ptychagnostus punctuosus* and *Goniagnostus nathorsti* zones in Västergötland, Sweden. Bull Geol Soc Denmark, 2004, 50: 39－45
44 Axheimer N, Eriksson M E, Ahlberg P, et al. The Middle Cambrian cosmopolitan key species *Lejopyge laevigata* and its biozone: new data from Sweden. Geol Mag, 2006, 143: 447－455[doi]
45 Babcock L E, Peng S C, Geyer G, et al. Changing perspectives on Cambrian chronostratigraphy and progress toward subdivision of the Cambrian System. Geosci J, 2005, 9: 101－106[doi]
46 Blacker M R, Peel J S. Cambrian trilobite from North Greenland. Medd Grønland Geosci, 1997, 35: 1－145
47 Zhou Z Y, Zhen Y Y. Trilobite Record of China. Beijing: Science Press, 2008
48 Duan J Y, An S L, Liu P J, et al. The Cambrian stratigraphy, fauna and palaeogeography in eastern part of North China Plate (in Chinese). Hong Kong: Yayuan Publishing House, 2005
49 Cowie J W, Ziegler W, Boucot A J, et al. Guidelines and Statutes of the International Commission on Stratigraphy (ICS). Cour Forsch-Inst Senckenberg, 1986, 83: 1－14
50 Remane J, Bassett M G, Cowie J W, et al. Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). Episodes, 1996, 19: 77－81
51 Robison R A, Rosova A V, Rowell A J, et al. Cambrian boundaries and divisions. Lethaia, 1977, 10: 257－262[doi]
52 Peng S C, Zhou Z Y, Lin T R. Late Middle-Late Upper Cambrian chronostratography of China. In: Ahlberg P, Eriksson M, Olsson, eds. IV Field Conference of the Cambrian Stage Subdovosion Working Group, International Subcommission on Cambrian Startigraphy, Sweden, 24－31 Aug. 1998. Lund: The Geolibrary, Lund University, 1998. 25
53 Peng S C, Yuan J L, Zhao Y L. Taijiangian Stage: a new chronostratigraphic unit for the traditional Lower Middle Cambrian in South China (in Chinese). J Strat, 2000, 24: 56－57
54 Peng S C, Babcock L E. Cambrian Period. In: Ogg J, Ogg G, Gradstein F, eds. The Concise Geologic Time Scale. Cambridge: Cambridge University Press, 2008. 37－46
55 Geyer G, Shergold J. The quest for internationally recognized division of Cambrian time. Episodes, 2000, 23: 188－195
56 Peng S C. New Global subdivision on Cambrian chronostratigraphy. Bulletin of Chinese Academy of Sciences (in Chinese). Bull Chi Acad Sci, 2006, 21: 325－328
57 Li G X, Zhu M Y, Zhang J M, et al. Bio- and Carbon isotope stratigraphy of the lower Cambrian in eastern Yunnan and the subdivision of the first Series of the Cambrian. In: Jago J B, ed, South Australia 2006, XI International Conference of the Cambrian Stage Subdivision Working Group, 2006, Aug 14－24, South Australia. Geological Adelaide: Geological Society of Australia, South Australian Division, 2006: 20
58 Zhu M Y, Zhang J M, Tang A H, et al. The first Series of the Cambrian of South China: Subdivision and Correlation. In: Jago J B, ed, South Australia 2006, XI International Conference of the Cambrian Stage Subdivision Working Group, 2006, Aug 14－24, South Australia. Geological Adelaide: Geological Society of Australia, South Australian Division, 2006. 43－44
59 Varlamov A I, Rozanov A Yu, Khomentovsky V V, et al. The Cambrian System of the Siberian Platform, Part 1: the Aldan-Lena Region. Moscow, Novisibirsk: PIN RAS Press, 2008