

Succession of Cambrian conodonts from South China

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Received July 20, 1999

Abstract More than 4 200 kg, the total weight, of 980 productive conodont samples mainly from four key sections in western Hunan and northwestern Hunan, South China have been processed. It is found that the paraconodonts occurring below Fengshanian (upper Upper Cambrian) may be used for stratigraphic subdivision and correlation. Accordingly, eight conodont zones ranging from upper Middle Cambrian to upper Upper Cambrian in South China are erected for the first time. The correlation between these zones and those of North China, North America and Iran is discussed. These eight zones are in ascending order as follows:

Gapparodus bisulcatus-*Westergaardodina brevidens* zone, *Shandongodus priscus*-*Hunano-gnathus tricuspidatus* zone, *Westergaardodina quadrata* zone, *Westergaardodina matsushitai*-*W. grandidens* zone, *Westergaardodina proligula* zone, *Westergaardodina* cf. *behrae*-*Prooneotodus rotundatus* zone, *Proconodontus* zone, *Cordylodus proavus* zone.

Keywords: Cambrian conodonts, South China.

The difficulty of the study on biostratigraphy of Cambrian conodonts is the zonation of the paraconodonts occurring below the Fengshanian (upper Upper Cambrian). The zonation of the primitive euconodonts occurring in the strata corresponding to the Fengshanian (upper Upper Cambrian), was finished abroad in the 1980s and was perfected later on. In addition to the two established conodont zones, several subzones of each zone were erected^[1, 2]. Since 1983, these zones and subzones have been successively recognized and proposed in China^[3-5]. Wang summed up this situation in 1990^[6]. Many conodont workers have considered for a long time that the Cambrian paraconodonts are all long-ranging elements, which cannot be used for stratigraphic subdivision and correlation. The main reasons for the above may be twofold. The first is the matter of geological conditions. The routine technique of etching with acetic acid for conodonts is only suitable for processing carbonates on a large scale (because the dolostones are generally rare or absent in conodonts, it is suitable only for processing limestone on a large scale). However, the continuously deposited sections, mainly consisting of limestone, of Middle through Upper Cambrian have been found only in a few countries, including China. Conodont experts of America and Europe have not found ideal sections for study on the biostratigraphy of Cambrian paraconodonts. In America and Europe, the areas for study on Cambrian paraconodonts in Sweden should be second to none. The initiator of research on Cambrian conodonts in the world Müller and his student Hinz systematically studied the conodonts of the Upper Cambrian in Sweden. As the conodont

samples were collected from numerous scattered interlayered thin-bedded limestones and nodules of orsten, and the lithology varies within short distance, it was impossible to sample in a vertical section with detailed measurements in the various outcrops. The horizons of conodont samples was determined on the basis of the occurring trilobites. Since the Upper Cambrian in Sweden is condensed succession, there is the phenomenon of mixture of the different nominated zonal species, with even the trilobite of Middle Cambrian in age being found in the Upper Cambrian^[7]. Therefore, that the conodonts are long-ranging is possible due to sampling and mixture of the conodont elements. It is impossible to generate conodont zones in this situation. However, An^[8] made good use of the favorable geological condition of North China and Northeast China. Mainly on the basis of four key sections in Liaoning, Hebei and Shandong, An erected the conodont zones of the upper part of Middle Cambrian Zhangxian through Upper Cambrian Fengshanian in 1982, among which the paraconodont zones below Fengshanian were those established for the first time in the world. The second is the intensity of research work. As mentioned previously, the geological conditions of Sweden are not ideal for the study on the biostratigraphy of Cambrian conodonts. Owing to the refined work of Müller and Hinz, they concluded: "Nevertheless, a number of species are useful to indicate stratigraphic position within the series". It is obvious that the more intensified work led to the change of their knowledge.

In South China, the southeast stratigraphical region is characterized by flyschoid formation. The Middle and Upper Cambrian are mainly composed of dolostone in the Yangzi stratigraphical region. (Only in the Langyashan subregion, the Middle and Upper Cambrian mainly consist of dolomitic limestone). The upper part of Middle Cambrian through Upper Cambrian is made up chiefly of limestones in the Danzai-Baojing-Qinyang subregion of the Jiangnan stratigraphical region, within which the well-developed and continuously deposited sections have been mainly found in Western Hunan and Northwestern Hunan. Accordingly, western Hunan and northwestern Hunan are the ideal areas for study on the Cambrian conodonts of South China. Trilobite biostratigraphy has been studied for more than 40 years in these areas, and the research is already exhaustive now. However, the research on the conodont biostratigraphy was fairly frail before the late 1980s in these areas. Only An Taixiang et al. studied two sections, in Luoyixi, Guzhang county, and in Likouzui, Fenghuang county in Hunan. Because they recovered only a few conodonts, it was impossible to erect the conodont zones^[9, 10]. Since 1985, the author has been studying the Cambrian conodonts from these areas and has published a small amount of his findings^[11-13]. Based on the regional investigation for a long time, the author selected four sections in Hunan as key sections, which are respectively the Paibi Section in Huayuan county, Xiaoxi Section in Jishou, Wangcun Section in Yongshun county and Wa'ergang Section in Taoyuan county. He also selected two sections in Hunan as auxiliary sections which are Xiaoxiqiao Section in Qianzhou and Yangjiazhai Section in Jishou, and two sections in Hunan as reference sections which are Tieqiao to Liangshuijing Section in Fenghuang county and Huaqiao Section in Baojing county (fig. 1).

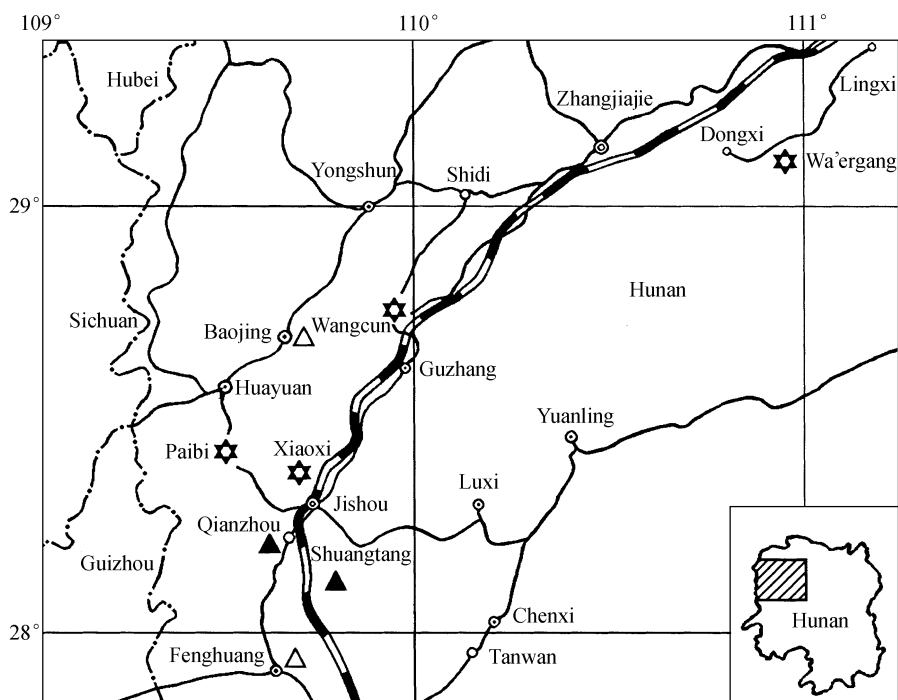


Fig. 1. Location of the studied section. ☆, Location of the key section; ▲, location of the auxiliary section; △, location of reference section.

1 Material and method

The above four key sections have been systematically collected for conodont samples three to four times, while the two auxiliary sections have been systematically collected only one time. In the Middle Cambrian Huaqiao formation, Upper Cambrian Chefu Formation and Shenjiawan Formation, the average sampling interval is 2 m and the average weight of samples is 4.6 kg. In the Upper Cambrian Bitiao Formation, the average sampling interval is 3 m and the average weight of samples is 4 kg. 980 productive conodont samples have been collected and the total weight of them is more than 4 200 kg.

In the studied areas, there are mainly five types of lithology from the Middle Cambrian Huaqiao Formation to the Upper Cambrian Shenjiawan Formation.

(i) Dark gray thin-bedded to medium-bedded laminated argilliferous very fine to fine crystalline limy dolostone. Only algae and protoconodonts without almost any other fossils occur in this type of lithology.

(ii) Alternate layers of dark gray medium-bedded laminated argilliferous dolostone, dark gray medium-bedded calcimicrite and biomicrite. The argilliferous dolostone yields only algae without any other fossils, whereas the limestones yield abundant conodonts as well as some trilobites, brachiopods, ostracods and small-shelly fossils.

(iii) Dark gray thin- to medium-bedded biomicrosparite, yielding extremely abundant cono-

donts as well as a number of trilobites, brachiopods, ostracods and phosphatocopine bradoriids, etc.

(iv) Gray thick-bedded calcirudite. Trilobites have been found occasionally in the gravel and matrix. No conodont samples have been collected in this type of lithology.

(v) Dark gray thin-bedded micrite intercalated with dark gray thin-bedded laminated dolomitic calcisiltite, bearing organic matter and scattered pyrite. Burrow and bioturbation may be found. The sedimentary structure such as nodular structure and pygmalion structure both formed by differential compaction is common in the field. The micrite yields abundant conodonts, as well as trilobites, brachiopods, small-shelly fossils, sponge spicules and radiolarians, etc.

Except for type (iv), the calcirudites, the above-mentioned other four types of lithology were all collected with certain sampling interval from the key sections and auxiliary sections in the first sampling. Mainly type (ii), type (iii) and type (v) were collected from the key sections in the second and third sampling. Mainly type (v) was collected from the sections in the fourth sampling. The purpose of the fourth sampling was to recover highly modified sponge spicules, Radiolaria and possibly phosphatized soft-integumented fossils, in addition to conodonts.

The samples were processed by routine etching with 10% technical acetic acid in plastic pail, 10 000 cm³ in volume. The cycle of sieving and changing acid was seven to ten days. The samples (including duplicate samples) generally need to be processed for three or four cycles, until they have been all dissolved. During the processing, the reaction time, pH value of the solution and the composition and content of the different buffer which is added to the solution, are adjusted according to the lab temperature (around 20°C in winter and up to 35°C in July and August). Some samples were processed in the plastic pails with three-layer screens. The results were very good. All the samples for the study on histology were processed in the plastic pails with three-layer screens.

2 Analysis of conodont fauna and conodont zonation

Based on the stratigraphical range of conodonts, the upper part of Middle Cambrian through Upper Cambrian in South China, is divided into eight conodont zones.

Upper Cambrian Series

Shenjiawan Fm.

(8) *Cordylodus proavus* zone

(7) *Proconodontus* zone

Bitiao Fm.

(6) *Westergaardodina* cf. *behræ*- *Prooneotodus rotundatus* zone

(5) *Westergaardodina prolifera* zone

Chefu Fm.

(4) *Westergaardodina matsushitai*-*W. grandidens* zone

(3) *Westergaardodina quadrata* zone

Middle Cambrian Series

Huaqiao Fm.

(2) *Shandongodus priscus*-*Hunanognathus tricuspidatus* zone(1) *Gapparodus bisulcatus*-*Westergaardodina brevidens* zone(1) *Gapparodus bisulcatus*-*Westergaardodina brevidens* zone

The first zone can be recognized in the lower part of Middle Cambrian Huaqiao Formation, respectively in the Paibi Section, Huayuan and Wangcun Sections, Yongshun in Hunan. Its lower limit is marked by the first appearance of *Gapparodus bisulcatus* and its upper limit is marked by the first appearance of *Shandongodus priscus*. The entire zone is characterized by the predominance of protoconodonts in quantity and the first appearance and higher diversity of paraconodont *Westergaardodina*. Its main elements are as follows:

Gapparodus bisulcatus, *G. sp. A.*, *Phakelodus tenuis*, *Ph. elongatus*, *Paibiconus proarcuatus*, *Westergaardodina brevidens*, *W. horizontalis*, *Hertzina ? sp. A.*, *Albiconus ? tricornis*, *Furnishina bigeminata*, *Gumella cuneata*.

(2) *Shandongodus priscus* - *Hunanognathus tricuspidatus* zone

This zone can be recognized in the upper part of Middle Cambrian Huaqiao Formation, in Paibi Section, Huayuan and Wangcun Sections, Yongshun in Hunan. Its lower limit is marked by the first appearance of *Shandongodus priscus* and its upper limit is marked by the last appearance of *Hunanognathus tricuspidatus*. It is characterized by the extreme diversity of paraconodonts and the maximum quantities of protoconodonts. Its main elements are as follows: *Shandongodus priscus*, *Westergaardodina sp. A.*, *W. sp. B.*, *W. tetragonia*, *W. compressa*, *W. cf. muelleri*, *W. aff. muelleri*, *Prosagittodontus sp.*, *Muellerodus ? obliquus*, *Furnishina cf. alata*, *F. kleithria*, *F. cf. kranzae*, *F. cf. vasmerae*, *F. pernica*, *F. cf. quadrata*, *Muellerodus oelandicus*, *M. pomeranensis*, *Hunanognathus tricuspidatus*, *Nogamiconus sinensis*, etc. In addition, there are elements occurring continuously from the underlying zone (1) upwards into this zone as follows: *Gapparodus bisulcatus*, *G. sp. A.*, *Gumella cuneata*, *Paibiconus proarcuatus*, *Albiconus ? tricornis*, *Furnishina bigeminata*, etc.

(3) *Westergaardodina quadrata* zone

This zone can be recognized in the lower part of Upper Cambrian Chefu Formation, respectively in Paibi Section, Huayuan, Wangcun Section, Yongshun, and Wa'ergang Section, Taoyuan, in Hunan. Its lower limit is marked by the first appearance of *W. quadrata* and its upper limit is marked by the first appearance of *W. matsushitai*. It is characterized by *W. quadrata* occurring in a great quantity, and *W. moessebergensis* and *W. tricuspidata* beginning to appear. Its main elements are as follows: *W. quadrata*, *W. moessebergensis* and *W. tricuspidata*. In addition, there are elements occurring continuously from the underlying zone upwards into this zone as follows: *Gapparodus bisulcatus*, *G. sp. A.*, *Gumella cuneata*, *Paibiconus proarcuatus*, *Albiconus ? tricornis*, *Westergaardodina sp. A.*, *W. cf. muelleri*, *Furnishina cf. alata*, *F. cf. quadrata*, *F. cf. kranzae*, *Nogamiconus sinensis*, *Prosagittodontus sp.* etc.

(4) *Westergaardodina matsushitai*-*W. grandidens* zone

This zone can be recognized in the upper part of Upper Cambrian Chefu Formation, respectively in Paibi Section, Huayuan, Wangcun Section, Yongshun and Wa'ergang Section, Taoyuan in Hunan. Its lower limit is marked by the first appearance of *W. matsushitai* and its upper limit is marked by the last appearance of *W. matsushitai*, *W. grandidens*. It is characterized by the obvious reduction of protoconodonts in quantity and by the occurrence of the specialized *Westergaardodina*. Its main elements are represented by *W. matsushitai*, *W. grandidens*, *W. cf. sp. A.*, *W. bisulcata*, *W. cf. matsushitai*, *Furnishina cf. pernica*, *Proacontiondus tortus*. In addition, there are elements occurring continuously from the underlying zone upwards into this zone including *Gapparodus bisulcatus*, *Gumella cuneata*, *Paibiconus proarcuatus*, *Albiconus ? tricornis*, *Furnishina cf. kranzae*, *F. cf. quadrata*, *F. cf. alata*, *Nogamiconus sinensis*, *Westergaardodina sp. A.*, *W. quadrata*, *W. cf. muelleri*, etc.

(5) *Westergaardodina proligula* zone

This zone can be recognized in the lower part of the Upper Cambrian Bitiao Formation, respectively in Wangcun Section, Yongshun and Wa'ergang Section, Taoyuan in Hunan. Its lower limit is marked by the last appearance of *W. matsushitai*, *W. grandidens*, and its upper limit is marked by the first appearance of *W. cf. behrae*. It is characterized by the obvious reduction of the diversity of *Westergaardodina*, i.e. the reduction of the quantity of the species of *Westergaardodina*. Its main elements are as follows: *Westergaardodina proligula sp. nov.*, *Muellerodus ? erectus*, *Coeloceradontus bicostatus*, *Prosagittodontus eureka*, *Furnishina furnishi*, *F. primitivus*. In addition, there are elements occurring continuously from the underlying zone upwards into this zone as follows: *Muellerodus pomeranensis*, *Gapparodus bisulcatus*, *Phakelodus tenuis*, *Ph. elongatus*, etc.

(6) *Westergaardodina cf. behrae*-*Prooneotodus rotundatus* zone

This zone can be recognized in the upper part of Upper Cambrian Bitiao Formation, especially in Wangcun Section, Yongshun and Wa'ergang Section, Taoyuan in Hunan. Its lower limit is marked by the first appearance of *W. cf. behrae*, while its upper limit is marked by the first appearance of euconodont *proconodontus*. It is characterized by the maximum quantities of the species of *prooneotodus*. Its main elements are as follows: *Prooneotodus rotundatus*, *P. gallatini*, *P. primitivus*, *Westergaardodina cf. behrae*, *Prosagittodontus primitivus*, *Muellerodus sp.*, Gen nov. A, *Furnishina curvata*, etc. In addition, there are elements occurring continuously from the underlying zone upwards into this zone as follows: *Coeloceradontus bicostatus*, *Furnishina furnishi*, *Phakelodus tenuis*, *Ph. elongatus*, *Gapparodus bisulcatus*, etc.

(7) *Proconodont* zone

This zone can be recognized in the lower part of Upper Cambrian Shengjiawan Formation, notably in the Wa'ergang Section, Taoyuan and Xiaoxi section, Jishou. Moreover, this zone also can be recognized in Upper Cambrian Cheshuitong Formation in Chuxian, Anhui^[14]. Its lower and upper limits are marked by the first appearance of *Proconodontus muelleri* and *Cordylodus proa-*

vus respectively. Its main elements are represented by *Proconodontus muelleri*, *Eoconodontus notchpeakensis*, *Teridontus nakamurai*, *Prosagittodontus dahlmani*, *P. dunderbergie*, *Proconodontus* sp. nov. A, *Procondotontus* sp. nov. B, etc. In addition, there are elements occurring continuously from the underlying zone upwards into this zone as follows: *Coeloceradontus bicostatus*, *Prooneotodus rotundatus*, *P. gallatini*, *P. primitivus*, *Phakalodus tenuis*, *Ph. elongatus*, etc.

(8) *Cordylodus proavus* zone

The last zone can be recognized in the upper part of Upper Cambrian Shenjiawan Formation, in the Wa'ergang Section, Taoyuan and Xiaoxi Section, Jishou. Moreover, this zone also can be recognized in Upper Cambrian Cheshuitong Formation in Chuxian, Anhui^[14]. Its lower and upper limits are marked by the first appearance of *Cordylodus proavus* and *Cordylodus intermedius* respectively. Its main elements are represented by *Cordylodus proavus*, *Cordylodus* sp. nov. A, *Cordylodus primitivus*, *Iaptognathus* sp. A, *Albiconus postcostatus*, *Eoconodontus* sp. nov. A, etc. In addition, there are elements occurring continuously from the underlying zone upwards into this zone such as *Proconodontus muelleri*, *Eoconodontus notchpeakensis*, *Prooneotodus rotundatus*, *P. gallatini*, *P. primitivus*, *Coeloceradontus bicostatus*, *Teridontus nakamurai*, etc.

3 Correlation of the Cambrian conodont zones in South China and those in related areas

As shown in table 1, no conodont zones below Fengshanian (upper Upper Cambrian) have been established outside China. Consequently, the paraconodont zones (below Fengshanian) of South China are chiefly correlated to those of North China (An, 1982), whereas the euconodont zones of South China can be widely correlated to other related areas worldwide.

Table 1 Correlation of the Cambrian conodont zones in South China and those in North China, North America and Iran

Series	Stage	South China (this paper)	North China ^[8]	North America ^[2]	Iran ^[16]
Upper Cambrian	Fengshanian	<i>Cordylodus proavus</i>	<i>Cordylodus proavus</i>	<i>Cordylodus proavus</i>	Conodont assemblage zone 4
		<i>Proconodontus</i>	<i>Proconodontus</i>	<i>Proconodontus</i>	Conodont assemblage zone 3
	Changshanian	<i>Westergaardodina</i> cf. <i>behræ</i> - <i>Prooneotodus rotundatus</i>	<i>Westergaardodina</i> aff. <i>fossa</i> - <i>Prooneotodus rotundatus</i>		Conodont assemblage zone 2
		<i>Westergaardodina proligula</i>	<i>Muellerodus ? erectus</i>		Conodont assemblage zone 1
	Gushanian	<i>Westergaardodina matsushitai</i> - <i>W. grandidens</i>	<i>Westergaardodina matsushitai</i>		
		<i>Westergaardodina quadrata</i>	<i>Westergaardodina oryigma</i>		
Middle Cambrian	Zhangxian	<i>Shandongodus priscus</i> - <i>Hunanognathus tricuspidatus</i>	<i>Shandongodus priscus</i>		
			<i>Laiwugnathus laiwuensis</i>		
	Xuzhuangian (upper part)	<i>Gapparodus bisulcatus</i> - <i>Westergaardodina brevidens</i>			

(1) *Gapparodus bisulcatus* - *Westergaardodina brevidens* zone

This zone shares few elements with the *Laiwugnathus laiwuensis* zone of North China. As the upper limits of both this zone and the *L. laiwuensis* zone are all marked by the first appearance of *Shandongodus priscus*, the upper limits of both zones may be correlated to each other. In Hunan, the lowest occurrence of *Gapparodus bisulcatus* is in the lowermost part of the Middle Cam-

brian Huaqiao Formation and is lower than the lowest occurrence of trilobite *Ptychagnostus atavus*. The *Ptychagnostus atavus* zone in Hunan corresponds to that in western Zhejiang^[15]. The *Ptychagnostus atavus* zone in western Zhejiang is equivalent to the *Beiliella* zone in North China. Accordingly, it is inferred that the lower part of the *Gapparodus bisulcatus*-*Westergaardodina brevidens* zone is identical with the upper part of Xuzhuangian in North China.

(2) *Shandongodus priscus* - *Hunanognathus tricuspis* zone

As this zone shares the zonal species *Shandongodus priscus* with the *Shandongodus priscus* zone in North China, the two zones can be easily correlated to each other. The lower limits of the two zones are all marked by the first appearance of *Shandongodus priscus*, so the lower limits of both the zones correspond precisely to each other. The upper limit of the former is marked by the last appearance of *Hunanognathus tricuspis*, and this horizon is a little lower than that of the first appearance of *Westergaardodina quadrata* in Hunan. *W. quadrata* and *W. orygya* are associated with one another and their first appearance is at the same horizon. The upper limit of *Shandongodus priscus* zone is a little lower than the horizon of the first appearance of *W. orygya* in North China. Accordingly, the upper limit of *Shandongodus priscus*-*Hunanognathus* zone in Hunan is identical to that of *Shandongodus priscus* zone in North China.

(3) *Westergaardodina quadrata* zone

This zone shares *W. quadrata* and *W. moessebergensis* with the *W. orygya* zone in North China. *W. quadrata* and *W. orygya* are characterized by their joint occurrence and basically the same range in North China. Consequently, the *W. quadrata* zone in South China is equivalent to the *W. orygya* zone in North China. As mentioned above, the lower limits of both correspond precisely to each other. As the upper limits of both are all marked by the first appearance of *W. matsushitai*, they are completely correlated to each other.

(4) *Westergaardodina matsushitai*-*W. grandidens* zone

This zone shares *W. matsushitai* with the *W. matsushitai* zone in North China. As mentioned above, the lower limits of both the zones are completely correlated to each other. The upper limit of the former is marked by the last occurrence of *W. grandidens* and *W. matsushitai*, so it is identical with the upper limit of the latter. Therefore, this zone is correlated to the *W. matsushitai* zone in North China.

Müller (1973) established seven assemblage zones of Late Cambrian through Early Ordovician in Iran. Assemblage zone 1 includes *Furnishina* sp. and *Westergaardodina moessebergensis*. Müller and Hinz^[7] excluded *Furnishina furnishi* named by Müller (1973) in Iran from this species^[16]. *W. moessebergensis* is a cosmopolitan species. In Hunan, *W. moessebergensis* and *W. quadrata* occur simultaneously. In other areas, *W. moessebergensis* occurs upwards for a longer range. This species may occur upwards into the *W. matsushitai* zone in North China. Accordingly, Assemblage zone 1 is roughly identical with both the *W. orygya* zone and the *W. matsushitai* zone in North China, and is approximately equivalent to both the *W. quadrata* Zone and *W. matsushitai*-*W. grandidens* zone in South China. As the lowest occurrence of *W. moessebergensis* corresponds

to the lower limit of trilobite *Agnostus pisiformis* zone all over the world, the lower limit of assemblage zone 1 is identical with that of *W. quadrata* zone in South China.

(5) *Westergaardodina proligula* zone

This zone shares the zonal species *Muellerodus ? erectus* of the *Muellerodus ? erectus* zone in North China, so the two zones can be correlated to each other. The lower limit of the former is marked by the last occurrence of *W. matsushitai* and *W. gramdidens*, while the lower limit of the latter is marked by the last occurrence of *W. matsushitai*. Accordingly, the lower limits of both are identical. The upper limit of the former is marked by the first appearance of *W. cf. behrae*, whereas the upper limit of the latter is marked by the last appearance of *Muellerodus ? erectus*. The upper limits of both zones approximately correspond to each other.

(6) *Westergaardodina cf. behrae-Prooneotodus rotundatus* zone

This zone mainly shares abundant *Prooneotodus rotundatus*, *P. gallatini*, etc. with the *Westergaardodina aff. fossa-Prooneotodus rotundatus* zone in North China. As mentioned above, the lower limits of both the zones (i. e. the upper limits of the underlying zones) are roughly equivalent to each other. The upper limits of both the zones are all marked by the first appearance of euconodont *proconodontus*, so they can be correlated precisely.

Assemblage zone 2 erected by Müller (1973) includes *Furnishina furnishi* (originally assigned to *F. assymetrica*, and reassigned to this species in 1991^[7]). *F. furnishi* is the common element in the *W. proligula* and *W. cf. behrae-Prooneotodus rotundatus* zone of this paper. Accordingly, assemblage zone 2 is roughly equivalent to the two zones of this paper.

(7) *Proconodontus* zone

This zone mainly shares the primitive euconodonts such as *Procondontus mulleri*, *Eoconodontus notchpeakensis*, *Teridontus nakamurai*, etc. Therefore, both zones can be easily correlated to the other. The lower and upper limits of both zones correspond to each other's. Both zones are also correlated to the zone of the same name in North America and to assemblage zone 3 in Iran (Müller, 1973).

(8) *Cordylodus proavus* zone

This zone mainly shares *Cordylodus proavus* with the zone of the same name in North China. Consequently, the two zones can be easily correlated to each other, and their lower and upper limits are equivalent to each other. Their lower limits are all marked by the first appearance of *C. proavus*, while their upper limits are all marked by the first appearance of *C. intermedius*. Both the zones are also correlated to the zone of the same name in North America and Assemblage zone 4 in Iran (Müller, 1973).

4 A brief review of the early evolution of conodonts in terms of morphology

The study of the morphological evolution of protoconodonts and paraconodonts is still in an embryonic stage, although they have been fairly well studied in taxonomy, histology and function. The paraconodont zones respectively erected in North and South China will enable us to execute

the study of the morphological evolution of paraconodonts on a sound ground. However, unlike that of euconodonts, the study of morphological evolution of paraconodonts has to be involved in the histological study to determine the mode of growth, except for the morphological characters and occurrence in time and space. Accordingly, the evolutionary relationship between the different genera and species has not been able to be determined based on the present intensity of study. The only thing we can do is to propose the evolutionary trends.

As early as 1984, Miller first proposed two broad and unequal evolutionary lineages of paraconodonts: the *Westergaardodina* lineage and a coniform paraconodont lineage^[17].

The present author (1988) discussed in limited space the evolutionary trends of proto- and para-conodonts^[18], among which the evolutionary trends of *Westergaardodina* was approved with minor revision by Müller and Hinz^[7]. Later on, he discussed the evolutionary trends of proto- and para-conodonts in more detail^[13].

Recently, An and Mei (1994) revised these two lineages into three lineages: *Laiwugnathus-Westergaardodina*, *Dolabrodus-Furnishina* and *Prooneotodus* lineages, based on the material of North China as well as South China^[19]. They overlooked the geological range and the paleogeographical distribution of the genera and species in their first two lineages, except for lacking of evidence of histology. For example, the lowermost horizon of the genus *Furnishina* (*Furnishina* sp.) is the trilobite *Triplagnostus gibbus* zone of Middle Cambrian in Sweden, corresponding to the middle and upper parts of Xuzhuang Stage in China^[15], whereas the lowermost horizon of the genus *Westergaardodina* (*Westergaardodina brevidens*) is in the middle part of the trilobite *Pseudophalacroma triangularis* zone^[11, 12], corresponding to the trilobite *Lioparia* Zone of the basal part of the Middle Cambrian Zhangxia Stage^[15]. In other words, the lowermost horizons of *Furnishina* and *Westergaardodina* are respectively lower than those of *Dolabrodus* and *Laiwugnathus*. Therefore, it can hardly be imagined that *Dolabrodus* and *Laiwugnathus* are the ancestors of *Furnishina* and *Westergaardodina*, respectively.

In short, a great deal of work needs to be done to come to a complete understanding of the early evolution of conodonts in terms of morphology.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 49772083).

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