Rivista Italiana di Paleontologia e Stratigrafia
(*Research in Paleontology and Stratigraphy*)
vol. 123(1): 1-10. **March 2017**

CONODONTS FROM THE WA'ERGANG SECTION, CHINA, A POTENTIAL GSSP FOR THE UPPERMOST STAGE OF THE CAMBRIAN

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To cite this article: Bagnoli G., Peng S., Qi Y. & Wang C. (2017) - Conodonts from the Wa'ergang section, China, a potential GSSP for the uppermost stage of the Cambrian. *Riv. It. Paleontol. Strat.,* 123(1): 1-10.

Key words: Conodonts; Cambrian; Stage 10; Biostratigraphy; South China.

Abstract. Furongian (upper Cambrian) conodonts from the Shenjiawan Formation, Wa'ergang section, Taoyuan County, Hunan Province, South China are described. The Wa'ergang section has been proposed as a potential GSSP for the base of the uppermost stage of the Cambrian System, at the first appearance of the agnostoid trilobite *Lotagnostus americanus*. The Shenjiawan Formation consists of limestone with intercalations of marlstone and shale. The conodont yielding is low and the preservation is moderate. The conodont fauna includes proto-, para- and euconodonts. Conodont taxa characteristic of North China, South China and Korea occur together with cosmopolitan taxa. The biostratigraphic distribution of conodonts is directly correlated with the agnostoid trilobite biozones, with the base of the *Proconodontus posterocostatus* Zone very close to the base of the *Lotagnostus americanus* trilobite Zone.

Introduction

The International Subcommission on Cambrian Stratigraphy (ISCS) has recommended a four-fold subdivision of the Cambrian System (Babcock et al. 2005; Peng 2006; Peng et al. 2006; Babcock & Peng 2007). In the uppermost series of the Cambrian, the Furongian Series, the first two stages, the Paibian Stage (Peng et al. 2004) and the Jiangshanian Stage (Peng et al. 2012) have been ratified. The uppermost stage of the Cambrian is not defined yet and is provisionally termed as Stage 10. The ISCS voted the FAD (First Appearance Datum) of the agnostoid cosmopolitan *Lotagnostus americanus* (Billings 1860), a senior synonym of *Lotagnostus trisectus*, as the marker for the base of Stage 10. Peng et al. (2014) proposed the Wa'ergang section, in Hunan Province, South China, as a potential candidate for the Global Standard Stratotype-Section and Point (GSSP) for the base of the uppermost Cambrian stage at the first appearance of *L. americanus*.

The main purpose of this paper is to describe the conodont succession recovered from a detailed sampling of the Wa'ergang section in the interval spanning the potential GSSP horizon. A second important purpose is to correlate the conodont fauna, based on direct evidence in the section, with the trilobite records.

Received: June 15, 2016; accepted: November 3, 2016

Location and Stratigraphy

The Wa'ergang section, Taoyuan County, Hunan Province, South China, is exposed along a roadcut in the village of Wa'ergang (Fig. 1). The succession is highly fossiliferous and comprises in ascending order the Aoxi, Huaqiao, Shenjiawan formations of Cambrian age, and the lower Ordovician Panjazui and Madaoyu formations.

Palaeogeographically, the Wa'ergang succession belongs to the northeastern part of the Jiangnan Slope Belt of the South China plate. The Jiangnan Slope Belt represents a low-latitude slope environment that contains a rich trilobite fauna, including cosmopolitan agnostoids which have intercontinental correlation utility (Peng et al. 2004). Biostratigraphically the Wa'ergang section embraces the *Ptychagnostus atavus* trilobite Zone through the *Hysterolenus* Zone (Peng et al. 2001).

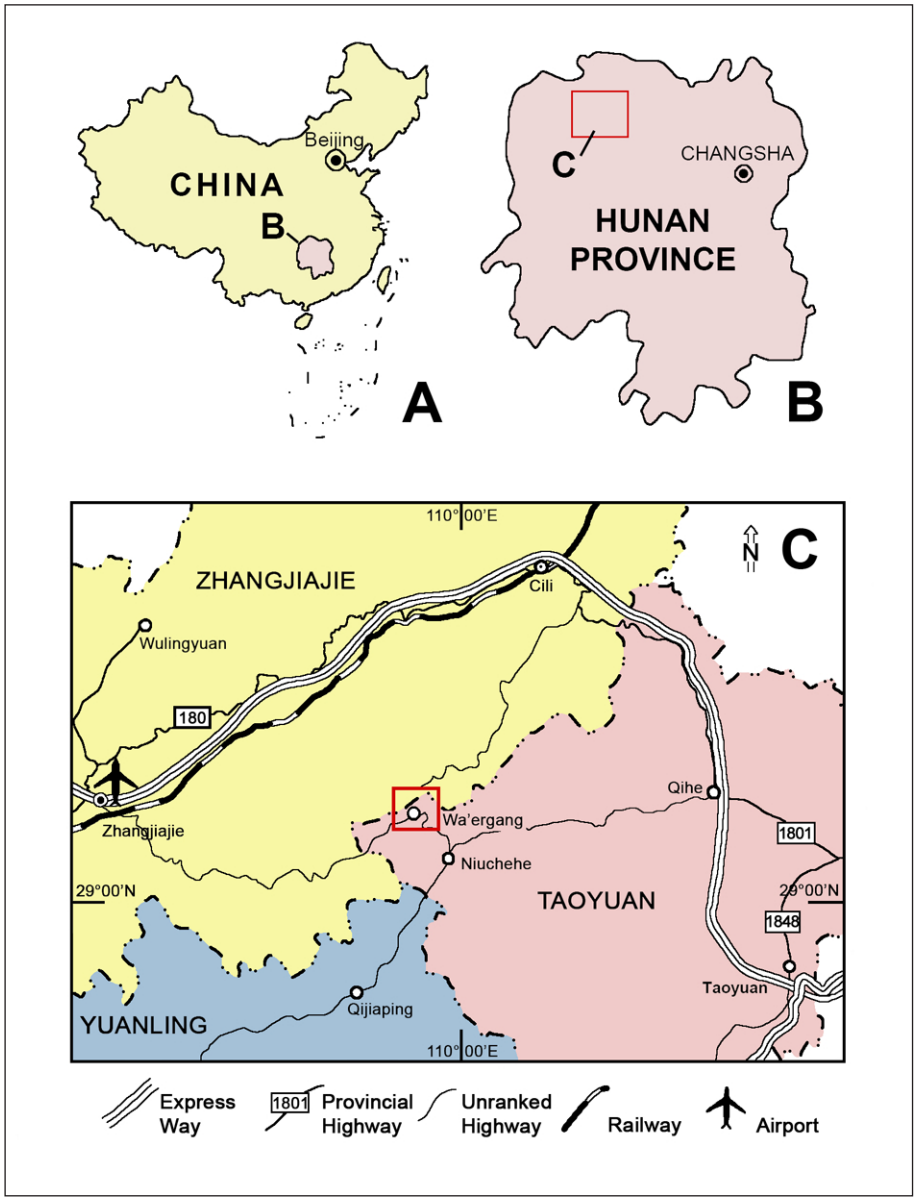


Fig. 1 - Location of the Wa'ergang section, Taoyuan County, Hunan Province, South China. A: Map of China with location of the Hunan Province. B: Map of Hunan Province; C: Detail of the area of study.

The investigated interval belong to the Shenjiawan Formation which is about 240 m thick (Fig. 2) and consists of thin- to medium-bedded, light-coloured limestone, dark-coloured laminated limestone, and nodular limestone with intercalations of marlstone and shale; a carbonate debris bed, 2-3 m thick, is developed in the upper part. The Shenjiawan Formation includes the *Eolotagnostus decorus*, the *Lotagnostus americanus*, the *Micragnostus chiushuensis*, the *Leiagnostus* cf. *L. bexelli-Archaeuloma taoyuanense*, the *Mictosaukia striata-Fatocephalus* and the *Leistegium constrictum-Shenjiawania brevis* trilobite zones (Peng et al. 2001; Peng et al. 2014). The FAD of *L. americanus* is 29.65 m above the base of the Shenjiawan Formation at a position of 29°06'42.8"N latitude and 109°55'17.5"E longitude.

MATERIAL AND METHODS

Except for the uppermost 22 m, the Shenjiawan Formation in the Wa'ergang section has been intensively collected for conodonts. 270 samples were collected from an interval of 237 m; in particular, the interval between 661.5 m and 800.3 m (138.8 m) was more densely sampled at intervals of about 0.5 m or less. Large samples (about 8 kg each in average) have been processed owing to the very low yielding (Tab. 1). The small number of conodont elements is possibly related to an inhospitable environment for the conodont animals. Standard techniques for conodont extraction have been applied and separation by means of heavy liquids was performed owing to the large amount of residue after acid digestion. 59 samples proved to be productive; of these 18 yielded only protoconodonts represented by *Phakelodus* spp. and they will not be considered further. The preservation is moderate and several specimens are completely or partly exfoliated making difficult their identification.

All specimens are deposited in Nanjing Institute of Geology and Palaeontology (NIGP), Chinese Academy of Sciences with reference number consisting of a prefix NIGP followed by a six digit number.

Tab. 1 - Numerical distribution of conodont elements from the Wa'ergang section.

Sample (m) \ Conodont taxa	*Dasytodus trasmutatus*	*Diaphanodus compressus*	*Diaphanodus* n. sp. A	*Eoconodontus notchpeakensis*	*Furnishina* sp.	*Granatodontus ani*	*Hirsutodontus nodus*	*Proacodus pulcher*	*Proconodontus muelleri*	*Proconodontus serratus*	*P. tenuiserratus bicostatus*	*Proconodontus* sp.	*Prooneotodus gallatini*	*Prooneotodus rotundatus*	*Rotundoconu s jingxiensis*	*"Teridontus gracilis"*	*Teridontus nakamurai*	*Westergaardodina* sp.	Total
872.1							1												1
872				1													1		2
860.1				1															1
856.9									1										1
852.5				1							1						2		4
830.9				1															1
830									1										1
814.3									1										1
808.2													2	1					3
808			3	6					1										10
806.9													1				1		2
804.2				1															1
803.6				1					3	2			1	1					8
802.2				1		2							1						4
800.3			2	2			1			1			2	4		1			13
798.8													2				1		3
796.2									1				3						4
794.5					1					1			4						6
791.5						1			1				2	1					5
775.5													3						3
770.2													2						2
769.5			1																1
767.3			2						1				2						5
755								1										1	2
716						1													1
712															1				1
711.5			3			2	1					1							7
710.3						2													2
707.9		2				2													4
702.1	1					1													2
695.5												1							1
685	1																		1
683.5		1																	1
676						1													1
675.9						3													3
675													1						1
673						1													1
669						2													2
664		1																	1
659.9						3							1						4
659.5						1						1							2
Total	2	4	11	15	1	22	3	1	10	4	1	3	27	7	1	1	5	1	119

Conodont fauna

The conodont fauna from the investigated interval includes protoconodonts, paraconodonts and euconodonts (Fig. 2). The lower part of the Shenjiawan Formation, from 659.5 m to 716 m, yielded *Diaphanodus compressus* (Chen & Gong, 1986), *Diaphanodus* n. sp. A, *Prooneotodus gallatini* (Müller, 1959), and is characterized by taxa ornamented with spines or grana, such as *Granatodontus ani* (Wang, 1985), *Hirsutodontus nodus* (Zhang & Xiang, in An et al. 1983), *Dasytodus trasmutatus* (Xu & Xiang, in An et al. 1983) and *Rotundoconus jingxiensis* An & Zhang, 1983 (in An et al. 1983). *D. trasmutatus* and *R. jingxiensis* are confined to the lower part. Only few incompletely preserved specimens of *Proconodontus* sp. have been recovered from this interval. *G. ani* is the most common species.

Samples from 716 m to 767.3 m yielded only *Phakelodus* spp., one specimen of *Proacodus pulcher* (An, 1982) and one specimen of *Westergaardodina* sp. These taxa do not provide a significant biostratigraphic resolution, and therefore this interval is considered as barren for euconodonts.

A change in faunal composition occurs in the upper part of the investigated interval, from 767.3 m to 872.1 m. *Proconodontus muelleri* Miller, 1969 first occurs at 767.3 m, followed by *Proconodontus serratus* Miller, 1969 and *Eoconodontus notchpeakensis* (Miller, 1969) at 794.5 m, and by *Teridontus nakamurai* (Nogami, 1967) at 798.8 m. *Diaphanodus* n. sp. A, *G. ani* and *H. nodus* continue from the lower interval. *Furnishina* sp., "*Teridontus gracilis*" (Furnish, 1938) sensu Chen & Gong, 1986 and *Proconodontus tenuiserratus bicostatus* Szaniawski & Bengtson, 1998 are present as single occurrences.

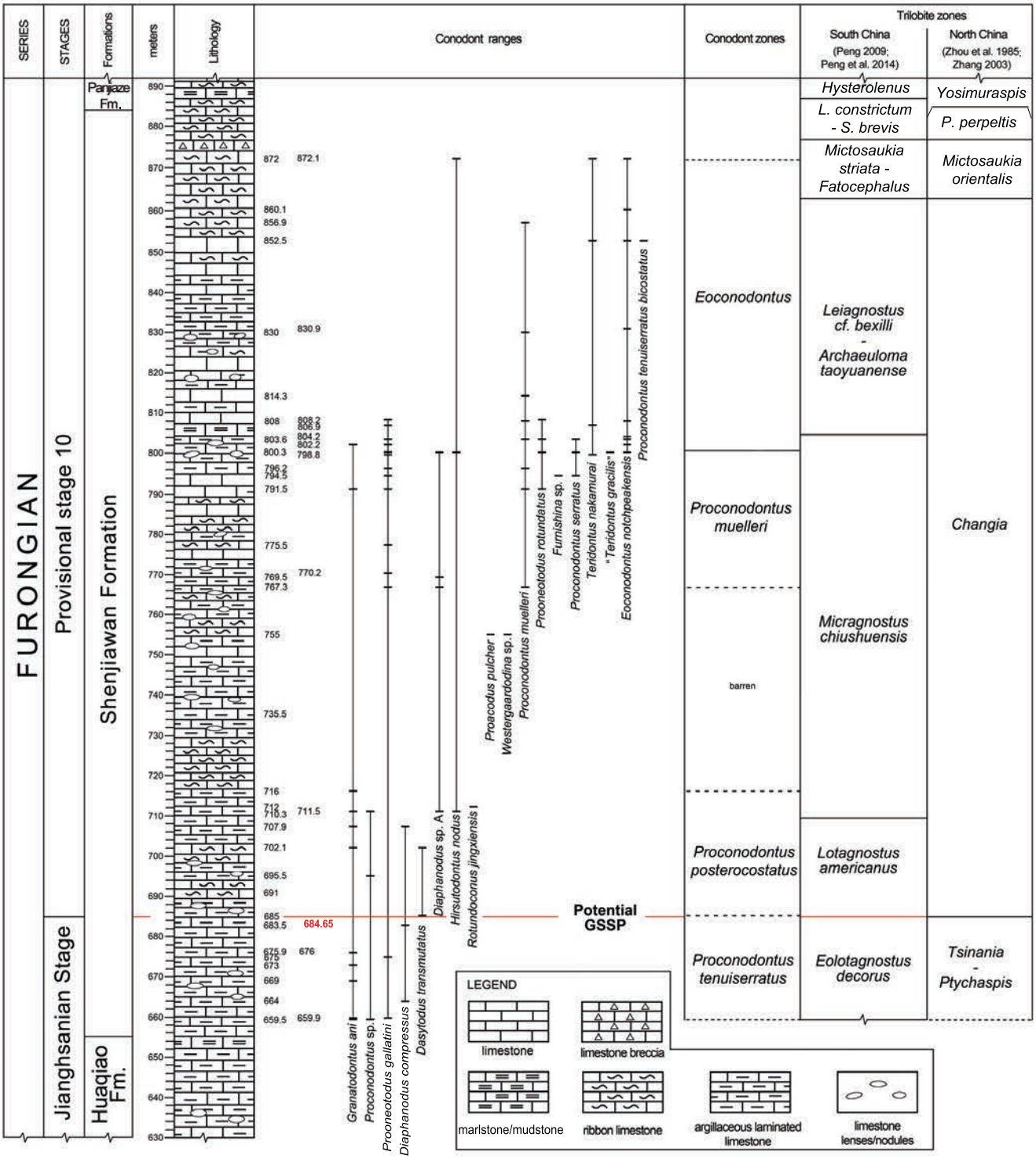


Fig. 2 - Stratigraphic distribution of conodonts in the Shenjiawan Formation, Wa'ergang section, conodont and trilobite biozones, and correlation with North China trilobite zonation. The distance between the base of the *Lotagnostus americanus* Zone and the base of the *Proconodontus posterocostatus* Zone is 35 cm and can not be appreciated in the figure. The line at the base of the *Proconodontus posterocostatus* Zone is dashed owing to the small number of conodont specimens recovered from this interval. In the trilobite zones *L.* refers to *Leiostegium, S.* to *Shenjiawania* and *P.* to *Pseudokoldinioidia.*

Conodont biostratigraphy

The succession from *Proconodontus tenuiserratus*, *Proconodontus posterocostatus*, *Proconodontus muelleri*, *Proconodontus serratus* to *Euconodontus notchpeakensis* is documented in several areas, such as North America (Miller 1980; Miller et al. 2003), North China (An 1982; Chen & Gong 1986), South China (Dong

et al. 2004), Korea (Lee & Lee 1988; Lee 2014) and Iran (Jahangir et al. 2015). The different authors proposed slightly different biozonal schemes that are mostly based on these cosmopolitan taxa (Fig. 3).

Our aim is to compare the conodont succession from the Wa'ergang section with the biostratigraphic schemes proposed for South China, North China and Korea. According to some palaeogeographic reconstructions, the South China (or Yangtze) block and the North China (or Sino-Korean) block belong to the Palaeozoic Gondwana (Scotese & McKerrow 1990; Laurie & Burrett 1992), whereas other models consider the Sino-Korean and Yangtze blocks as separate terranes away from Gondwana in the early Palaeozoic (Webby et al. 2000; Li & Powell 2001). Whether or not the two blocks were separated from Gondwana, the conodont faunas from these two areas share some endemic or characteristic taxa that can be useful for correlation and biozonation, particularly for the lower part of the investigated interval, where we did not record the zonal markers.

South China - Dong et al. (2004) established a Cambrian-Ordovician biostratigraphic scheme for South China based on sections from Hunan Province, including the Wa'ergang section. The Authors subdivided the interval under consideration into the *P. tenuiserratus*, *Proconodontus* and *Euconodontus* zones. The *P. tenuiserratus* Zone is defined at the base by the FAD of the nominal taxon, the base of the *Proconodontus* Zone is defined by the FAD of *P. muelleri*, and the base of the *Eoconodontus* Zone by the FAD of *E. notchpeakensis*. Dong et al. (2004) could not distinguish the *P. posterocostatus* Subzone and the *P. muelleri* Subzone of the *Proconodontus* Zone, as recognized in North China (Chen & Gong 1986), nevertheless they correlated their *Proconodontus* Zone with the *Proconodontus* Zone of North China and with the *Proconodontus posterocostatus* and *Proconodontus muelleri* zones of western U.S.A. (Miller 1988). Dong et al. (2004) reported the *P. tenuiserratus* Zone in the Wa'ergang section at the base of the Shenjiawan Formation. In our conodont collection, the nominal taxon of this zone has not been recorded, whereas we can positively recognize the *Proconodontus* and the *Eoconodontus* zones.

North China - An (1982) established the *Proconodontus* Zone corresponding to the interval comprised between the lowest occurrence of *Proconodontus* and *Hirsutodontus* and the lowest occurrence of *Cordylodus proavus*. Chen & Gong (1986) subdivided the interval under consideration into the *P. tenuiserratus* Zone, the *Proconodontus* Zone comprising the *P. posterocostatus* and *P. muelleri* subzones, and the *Cambroistodus* Zone, based on material from the Dayangcha section, Jilin Province, North China. The *P. tenuiserratus* Zone is marked at the base by the FAD of the nominal taxon and is characterized by the dominance of *Furnishina*, *Granatodontus* and *Prooneotodus*. The *P. posterocostatus* Subzone is marked at the base by the FAD of the nominal taxon. The FAD of *P. posterocostatus* coincides with the first appearance of *Dasytodus transmutatus* (Chen & Gong 1986: 108). The next subzone is marked by the FAD of *P. muelleri* and includes in the upper part the FAD of *E. notchpeakensis*. The *Cambroistodus* Zone is identified by the appearance of *Cambroistodus*. In the lower part of the Wa'ergang section, even though *P. tenuiserratus* and *P. posterocostatus* cannot be recognized,

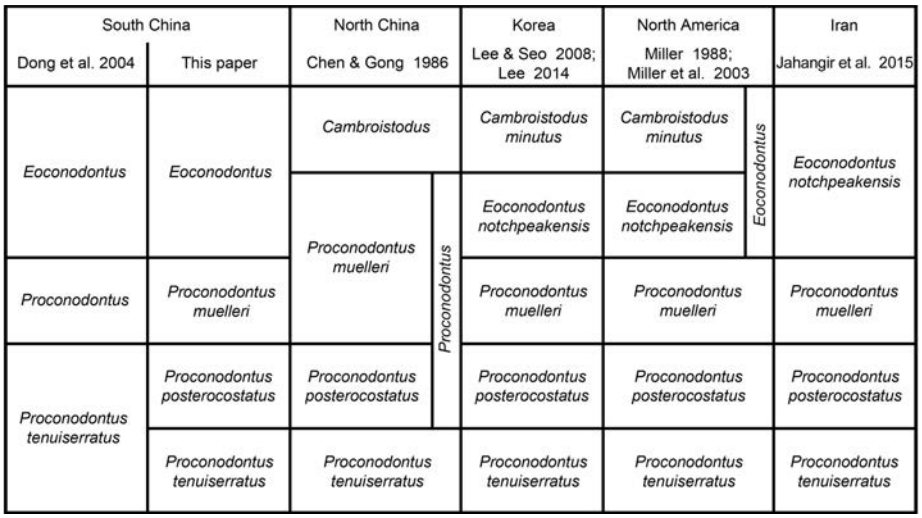


Fig. 3 - Conodont zonation of the Wa'ergang section and correlation with North China, Korea, North America and Iran.

the conodont succession is quite comparable with the succession from Dayangcha; in the Wa'ergang section, the lowermost assemblage is characterized by *Granatodontus*, followed by the first occurrence of *D. transmutatus* at 685 m at a level close to the proposed GSSP (684.65 m), thus allowing a confident correlation with the *P. posterocostatus* Zone of Chen & Gong (1986). Also the first occurrence of *Hirsutodontus nodus* (*Dasytodus nodus* in Chen & Gong 1986) in the upper part of the *P. posterocostatus* Zone is similar in the two sections. The upper part of the examined interval in the Wa'ergang section, is assigned to the *P. muelleri* and *Eoconodontus* zones because *Cambroistodus* was not recovered.

Korea - Lee (2014) divided the Hwajeol Formation in the Taebaeksan Basin, Korea into the *P. tenuiserratus, P. posterocostatus* and *P. muelleri* zones based on the nominal taxa. Also in this area *D. transmutatus* appears at the base of the *P. posterocostatus* Zone. Within this zone, *Rotundoconus jingxiensis* first occurs. Similarly, in the Wa'ergang section *R. jingxiensis* occurs within the *P. posterocostatus* Zone.

Correlation with trilobites

The occurrence in the Shenjiawan Formation at the Wa'ergang section of both conodonts and trilobites allows direct correlation between these two groups of fossils (Fig. 2). This biostratigraphically integrated approach might be useful for correlation with other paleogeographical regions, particularly those areas where agnostoid trilobites are not present. The trilobite biostratigraphy of the investigated interval has been established by Peng et al. (2014) and correlation with North China trilobite zones is based on Peng (2009) with some revisions (Fig. 2).

The lowermost part of the Shenjiawan Formation assigned to the *Proconodontus tenuiserratus* Zone corresponds to the upper part of the *Eolotagnostus decorus* trilobite Zone and correlates with the *Tsinania – Ptychaspis* trilobite Zone of North China.

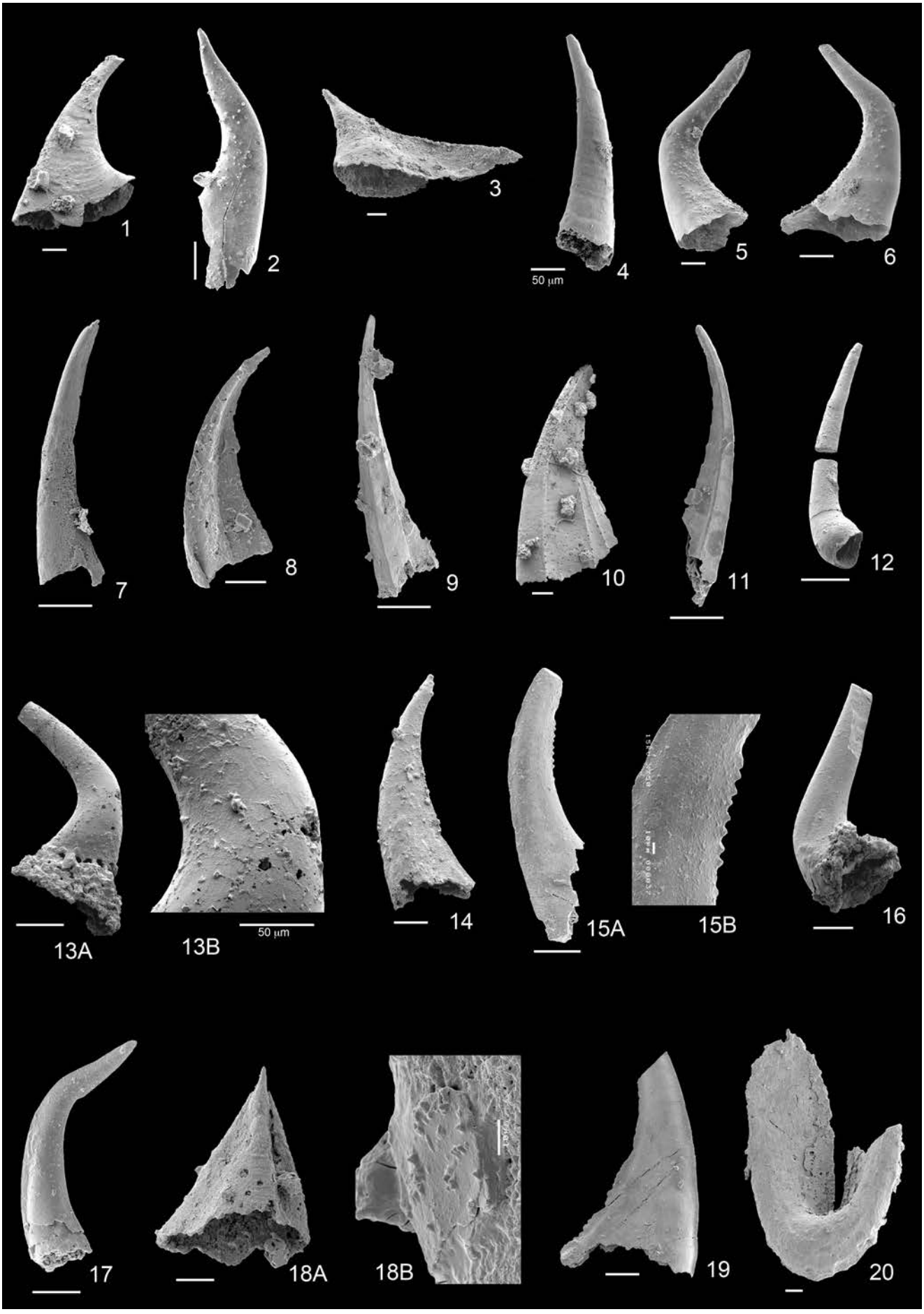
At 684.65 m the FAD of *Lotagnostus americanus* marks the base of the eponymous trilobite zone, the potential GSSP for the base of Stage 10. The base of the *Proconodontus posterocostatus* Zone is at 685 m, just 35 cm above the FAD of *L. americanus*. The *L. americanus* Zone correlates with the lower part of the *Changia* Zone in North China. Chen & Gong (1986: 108) reported the *Proconodontus posterocostatus* Subzone in the Dayangcha section from the *Quadraticephalus* (= *Changia*) Zone.

An almost barren interval prevents the recognition of the boundary between the *P. posterocostatus* and the *Proconodontus muelleri* Zones. The *P. muelleri* Zone, as recorded here, corresponds to the upper part of the *Micragnostus chiushuensis* trilobite Zone which correlates with the middle part of the *Changia* Zone in North China.

The base of the *Eoconodontus* Zone, marked by the first occurrence of *Eoconodontus notchpeakensis*, is close to the base of the *Leiagnostus* cf. *bexilli – Archaeuloma taoyuanense* trilobite Zone which correlates with the upper part of the *Changia* Zone.

PLATE 1

Scanning electron microphotographs of conodonts from the Wa'ergang section.
All specimens in lateral view, if not specified; white bar = 100 μm, if not specified.
Fig. 1 - *Prooneotodus gallatini* (Müller, 1959), 767.35 m, NIGP164426.
Fig. 2 - *Dasytodus transmutatus* (Xu & Xiang, in An et al. 1983), 685 m, NIGP164427.
Fig. 3 - *Proacodus pulcher* (An, 1982), 755 m, NIGP164428
Fig. 4 - *Prooneotodus rotundatus* Druce & Jones, 1971, 791.5 m, NIGP164429.
Fig. 5, 6 - *Granatodontus ani* (Wang, 1985), 5) 710.3 m, NIGP164430; 6) 707.9 m, NIGP164431.
Fig. 7 - *Proconodontus* sp., 691 m, NIGP164432.
Fig. 8 - 10 - *Diaphanodus* n. sp. A, 8) 800.3 m, NIGP164433; 9) 711.5 m, NIGP164434; 10) 767.35 m, NIGP164435.
Fig. 11 - *Diaphanodus compressus* (Chen & Gong, 1986), 664 m, NIGP164436.
Fig. 12 - *"Teridontus gracilis"* (Furnish, 1938) sensu Chen & Gong (1986), 800.3 m, NIGP164437.
Fig. 13A-B - *Teridontus nakamurai* (Nogami, 1967), 798.85 m; B) detail with striae NIGP164438.
Fig. 14 - *Proconodontus muelleri* Miller, 1969, 796.25 m, NIGP164439.
Fig. 15A-B - *Proconodontus tenuiserratus bicostatus* Szaniawski & Bengtson, 1998, 852.5 m, B) detail of the denticles, NIGP164440.
Fig. 16 - *Hirsutodontus nodus* (Zhang & Xiang, in An et al., 1983), 800.3 m, NIGP164441.
Fig. 17 - *Eoconodontus notchpeakensis* (Miller, 1969), 860.1 m, NIGP164442
Fig. 18A-B - *Rotundoconus jingxiensis* An & Zhang, 1983 (in An et al. 1983), 712 m. A) posterior view; B) detail of the ornamentation, NIGP164443.
Fig. 19 - *Proconodontus serratus* Miller, 1969, 794.5 m, NIGP164444.
Fig. 20 - *Westergaardodina* sp. posterior view, 755 m, NIGP164445.


1
2
3
4
50 μm
5
6
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8
9
10
11
12
13A
13B
50 μm
14
15A
15B
16
17
18A
18B
19
20

Taxonomic notes

Genus *Diaphanodus* Bagnoli, Barnes & Stevens, 1987
Type species: *Stenodontus compressus* Chen & Gong, 1986

Remarks. This genus has been recently revised by Bagnoli & Stouge (2014) to include thin walled, strongly laterally compressed and keeled elements with deep basal cavity and with lateral carinae and/or costae. Bagnoli & Stouge (2014) assigned these specimens to the Genus *Stenodontus* Chen & Gong, 1986 not being aware that the name of the conodont genus is a junior homonym of an ichneumod wasp, *Stenodontus* Berthomieu, 1896. The first available name for this conodont genus is *Diaphanodus* Bagnoli, Barnes & Stevens, 1987 (Bagnoli et al. 2015).

Diaphanodus n. sp. **A**
Pl. 1, figs 8-10

Description. The specimens at hand comprise symmetrical and asymmetrical elements. The symmetrical elements have two or three costae on each side. Some elements are very slender, with two costae on each side extending up to the apex. Other elements, with antero-posteriorly extended base, have three costae on each side. In this kind of element, one costa is close to the anterior margin and extends up the apex, the other two are close to the posterior margin and are confined to the basal part. The asymmetrical element is more recurved and carries a costa only on one side. The costa reaches the apex and is medially located.

Remarks. *Diaphanodus* n. sp. A differs from *Diaphanodus compressus* (Chen & Gong, 1986) for the higher number of costae. The species is left in open nomenclature owing to the small number of specimens. Hook-like elements have not been recorded.

Occurrence. 711.5 m, 767.3 m, 769.5 m, 800.3 m, 808 m.

Material. 11 specimens.

Repository. NIGP164433-NIGP164435.

Genus *Proconodontus* Miller, 1969
Type species: *Proconodontus muelleri* Miller, 1969

Proconodontus tenuiserratus bicostatus
Szaniawski & Bengtson, 1998
Pl. 1, fig. 15 A, B

1998 *Proconodontus tenuiserratus bicostatus* subsp. n. Szaniawski & Bengtson, pp. 18-19, pl. 4, figs. 11-12, 14-16.
2011 *Proconodontus serratus* Miller, 1969 – Miller et. al., fig. 7: C, D.

Remarks. A single specimen conforms with *Proconodontus tenuiserratus bicostatus* Szaniwski & Bengtson, 1998 by having anterior and posterior keel developed. The anterior keel extends from the base to the tip of the element. The less extended posterior keel is finely serrated in the apical part with 10 small denticles regularly spaced.

Occurrence. 852.5 m

Material. 1 specimen.

Repository. NIGP164440.

Proconodontus sp.
Pl. 1, fig. 7

Remarks. The specimens at hand have a very thin crown, a rounded anterior margin and a posterior keel not completely preserved. The elements are poorly preserved and partly exfoliated thus preventing a specific identification.

Occurrence. 659.5 m, 695.5 m, 711.5 m.

Material. 3 specimens.

Repository. NIGP164432.

Genus *Rotundoconus*
Type species: *Rotundoconus jingxiensis* An & Zhang in An et al. 1983

Rotundoconus jingxiensis
An & Zhang in An et al., 1983
Pl. 1, fig. 18 A, B

1983 *Rotundoconus jingxiensis* gen. et sp. n. An & Zhang (in An et al. 1983), pp.135-136, pl. 3, figs. 7, 8, text-fig. 9: 19-20.
1988 *Rotundoconus jingxiensis* – Lee & Lee, pl. 1, figs 30-34.
1989 *Rotundoconus jingxiensis* - Lee, pl. 1, figs. 4-5.
2008 *Rotundoconus jingxiensis* – Lee, text-fig. 1: 5.
2008 *Rotundoconus jingxiensis* – Lee & Seo, pl. 1, figs. 3, 4.
2014 *Rotundoconus jingxiensis* – Lee, pl. 1, figs. 26, 27.

Remarks. Tricarinate element almost completely exfoliated except in small areas (Pl. 1, Fig. 18B) where the ornamentation with minute nodules typical of *Rotundoconus* can be observed.

Occurrence. 712 m

Material. 1 specimen

Repository. NIGP164443.

Concluding remarks

The conodont fauna recovered from the Shenjiawan Formation at the Wa'ergang section is assigned to the *Proconodontus tenuiserratus*, *Proconodontus posterocostatus*, *Proconodontus muelleri* and *Eoconodontus* zones. The *P. tenuiserratus* Zone can be recognized by the presence of few poorly preserved *Proconodontus* sp. and the dominance of *Granatodontus ani*. The base of the *P. posterocostatus* Zone is identified by the first occurrence of *Dasytodus transmutatus*. The FAD of *D. transmutatus* in North China and Korea coincides with the FAD of *P. posterocostatus*. The *P. muelleri* Zone is recognized by the presence of the index taxon. An almost barren interval occurs between the *P. posterocostatus* and the *P. muelleri* zones. The *Eoconodontus* Zone is marked by the occurrence of *E. notchpeakensis*.

The Wa'ergang section has been proposed as a potential stratotype for the base of the uppermost stage of the Cambrian System, at the FAD of the agnostoid trilobite *Lotagnostus americanus*. The sections fulfils all the requirements for a GSSP including a good exposure mainly along a roadcut, easy accessibility by ordinary vehicles, apparent continuous deposition with no evidences of gaps or tectonic disturbance, and detailed documentation of the faunal succession. The occurrence of conodonts, even though rare, contributes to improve correlation with areas and depositional settings where agnostoid trilobites are not present. In this perspective, it is significant that the base of the *P. posterocostatus* Zone is a short distance (35 cm) above the base of the *L. americanus* Zone.

Aknowledgments. This work was supported by grants to Peng Shanchi from the National Natural Science Foundation of China (41330101, 41521061, 41290260) and the Ministry of Science and Technology of China (2015FY31010), and to Qi Yuping from the National Natural Science Foundation of China (41072009, 40772005). The authors wish to thank Tatiana Tolmacheva, an anonymous referee and the editor for their constructive reviews.

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