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

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

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.

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).
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 *Eolagnostus decorus*, the *Lotagnostus americanus*, the *Micragnostus chiuhsuensis*, the *Leiagnostus cf. L. bexelli-Archaeuloma taoyuanense*, the *Mictosaukia striata-Fatocephalus* and the *Leistegium constructum-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.
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 Phakesodus 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 nakamura (Nogami, 1967) at 798.8 m. Diaphanodus n. sp. A, G. ani and H. nodus continue from the lower interval. Furnishina sp., “Teridonous gracilis” (Furnish, 1938) sensu Chen & Gong, 1986 and Proconodontus tenuissimus biostatus Szaniawski & Bengtson, 1998 are present as single occurrences.

Tab. 1 - Numerical distribution of conodont elements from the Wa’ergang section.
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 1988).
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 (Seo et al. 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 Eoconodontus 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 Cordyloodus praevus. 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 Dayangha 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 Prooneodontus. The P. posterocostatus Subzone is marked at the base 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,}

<table>
<thead>
<tr>
<th>South China</th>
<th>North China</th>
<th>Korea</th>
<th>North America</th>
<th>Iran</th>
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<tbody>
<tr>
<td>Dong et al. 2004</td>
<td>This paper</td>
<td>Chen &amp; Gong 1986</td>
<td>Lee &amp; Seo 2008; Lee 2014</td>
<td>Miller 1988; Miller et al. 2003</td>
</tr>
<tr>
<td>Eoconodontus</td>
<td>Eoconodontus</td>
<td>Cambroistodus</td>
<td>Cambroistodus minutus</td>
<td>Cambroistodus minutus</td>
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<td>Proconodontus muelleri</td>
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<td>Proconodontus tenuiserratus</td>
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<td>Proconodontus tenuiserratus</td>
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<td>Proconodontus tenuiserratus</td>
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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 *Granatodus*, 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 *Hirsutodus 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 Taebaek 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 whereagnostoid 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 *Eoagnostus decorus* trilobite Zone and correlates with the *Tsimania – 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 *Quadratecephalus (= 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 *Miroagnostus 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. beccili – Archaeoloma taoyuanense* trilobite Zone which correlates with the upper part of the *Changia* Zone.

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**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 - *Proconodus galatini* (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 - *Proconodontus rotundatus* Druce & Jones, 1971, 791.5 m, NIGP164429.
Fig 5, 6 - *Granatodus 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, B* 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 & Bengston, 1998, 852.5 m, B) detail of the denticles, NIGP164440.
Fig 16 - *Hirsutodus 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.
Cambrian conodonts from the Wu'ergang section (China)
**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 ichneumon 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* Szaniawski & 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**


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.

Acknowledgments. 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 (2015FY1010), and to Qi Yaping 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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