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# A proposed GSSP for the base of the Middle Ordovician Series: the Huanghuachang section, Yichang, China

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*The Huanghuachang section near Yichang, southern China meets the requirements of Global Stratotype Section and Point (GSSP) for the base of the Middle Ordovician Series and the yet-to-be-named third stage of the Ordovician System (or lower stage of Middle Ordovician Series). The conodont succession at the section is complete across the Lower to Middle Ordovician series boundary and several excellent phylogenetic lineages of Baltoniodus, Trapezognathus, Periodon, and Microzarkodina are represented. The definition of the base of the Middle Ordovician is proposed to be the first appearance datum (FAD) of Baltoniodus? triangularis in the section. It is followed closely by the FAD of Microzarkodina flabellum, which is taken as a reasonable proxy for the boundary. This level approximates the boundary between the lower and upper intervals of the Azygograptus suecicus graptolite Biozone, and nearly coincides with the base of the Belonechitina henryi chitinozoan Biozone. The proposed GSSP for the base of the international Middle Ordovician Series is located in a roadside exposure at the base of Bed (SHod) 16, 10.57 m above the base of the Dawan Formation in the measured Huanghuachang section near Yichang City, southern China. The same faunal succession is also recorded from the Chenjiahe (formerly Daping) section, 5 km to the north of the Huanghuachang section. The proposed boundary horizon can be recognized and correlated globally with high precision in both relatively shallow-water carbonate facies as well as in deep-water graptolite facies.*

## Introduction

Since 1989, the Subcommittee on Ordovician Stratigraphy (ISOS) of the International Commission on Stratigraphy (ICS) has been involved in an extensive project with the goal of establishing globally applicable stage and series subdivisions for the Ordovician System (Webby, 1994). The task of identifying suitable levels for series and/or stage subdivision has been conducted by means of intra-Ordovician working groups. The working groups have made considerable progress and four Ordovician global stages—the Tremadocian (first

stage), the yet-to-be-named Second stage, the Darriwilian (fourth stage), and the yet-to-be-named Fifth stage—and two global series—the Lower Ordovician Series and the Upper Ordovician Series—have thus far been formally ratified by the ICS. Among the remaining series or stage, one focus is on the investigation and selection of the GSSP for the base of the Middle Ordovician Series, which also is the base of the Third stage. Two biozone levels that appear to have potential for reliable correlation of the base of the Middle Ordovician Series have been suggested by the working group of the ISOS: the base of *Tripodus laevis* conodont Biozone/*Isograptus v. lunatus* graptolite Biozone, and the base of the *Baltoniodus triangularis* conodont Biozone. The former was thought to coincide with the base of the North American Whiterock Series (Ross & Ethington, 1992; Ross et al., 1997), and the base of *B. triangularis* with the base of the Baltoscandian Volkhov Stage (Webby, 1994, 1995). After long discussions and a set of ballots and questionnaire circulated to the Voting Membership a formal Subcommittee postal ballot was held during October–December 1995 together with the ballot of the tripartite division of the Ordovician. The base of *T. laevis* Biozone was finally adopted by majority (82%) of voting members and then approved by the ISOS as the biozone for definition of the base of the Middle Ordovician Series (Webby, 1997, 1998). Afterwards, the Whiterock Narrows section in the Monitor Range, Nevada was first recommended as the stratotype for the base of the global Middle Ordovician Series with the boundary placed at the FAD of *Tripodus laevis*, 3 m below the top of the Ninemile Formation on the basis of tremendous effort devoted by the boundary working group (Finney & Ethington, 2000, 2001). The proposed boundary in the Whiterock Narrows section, however, has been proved to be younger than expected previously by newly collected graptolites 1.5 m above the proposed boundary level (Mitchell, 2001). Albanesi & Carrera (2001, 2003) proposed the Niqivil section, Argentina as the global stratotype for the base of the Middle Ordovician with the FAD of *Protoprioniodus aranda* as an alternative index species for the boundary level. Wang et al. (2002, 2003a) recommended the Huanghuachang section, China as the potential GSSP for the base of the Middle Ordovician Series with the FAD of *Baltoniodus triangularis* as the boundary biomarker. Zhen et al. (2003) recently revised *P. aranda* originally erected by Cooper (1981) and allocated the species into new genus *Cooperignathus*, resulting in some confusion with regard to the concept of this species.

The recommended Huanghuachang section has excellent and well-known conodont, chitinozoan, graptolite, acritarch and other shelly fossil records in a stratigraphically continuous succession. *Oepikodus communis*, *Oepikodus evae*, *Oepikodus intermedius*, *Juanognathus variabilis*, *Gothodus* spp., *Tropodus* spp., *Tripodus* cf. *laevis*, *Reutterodus andinus*, *Lundodus gladius*, *Trapezognathus diprion*, *Baltoniodus? triangularis*, *Baltoniodus navis*, *Microzarkodina flabellum*, *M. sp. A* and *Periodon* spp. are all found

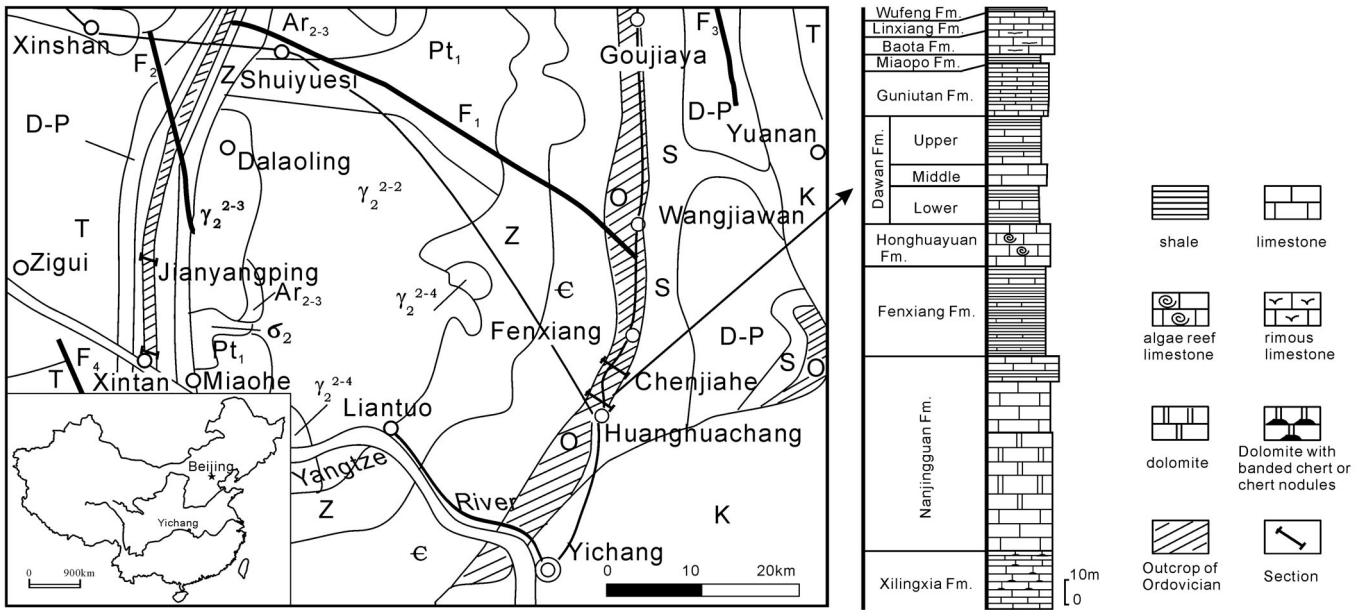


Figure 1 Sketch geological map in Yichang Area, Hubei, China with the localities of the Huanghuachang and adjacent sections, and the Ordovician succession of the Huanghuachang section.

in the section. The conodont succession across the proposed boundary interval is well developed with several evolving lineages, including those from *Trapezognathus diprion* to *Baltoniodus? triangularis*, from *Periodon flabellum* to *Periodon* sp.A, from *Microzarkodina* sp. A to *Microzarkodina flabellum* and from *Baltoniodus* n. sp. A to *Baltoniodus navis*. The proposed boundary biohorizon is taken as the FAD of *Baltoniodus? triangularis*, which corresponds to the base of the *Baltoniodus? triangularis-Microzarkodina flabellum* Biozone in the Huanghuachang section. This level is similar to that proposed by Webby (1994, 1998) as a boundary marker and coincides with the base of the *Tripodus laevis* (Bergström, 1995).

## Location, history of study and geological setting of recommended GSSP

### Location of the recommended GSSP

The recommended Huanghuachang section is located along the major road from Yichang City to Xinshan County, 22 km NE of Yichang City, Hubei Province, China (Figure 1), and can easily be accessed by car. Yichang City, situated at the entrance of the Yangtze Gorges, is the largest hydroelectric city and one of the most well-known tourist cities in China. It can be reached by major highway, train, and regular direct flights from Beijing, Shanghai and Guangzhou.

### History of studying

The Huanghuachang section has been studied in great detail for almost 50 years (Zhang et al., 1957; Mu et al., 1979; Wang, 1980, Zeng et al., 1983; Wang et al., 1987, 1992a,b, 1996; An, 1987). It is in the type area for the subdivision of the Ordovician System in China, and can be correlated confidently with other sections in the region. It is characterized by an uninterrupted succession of strata across the Lower/Middle Ordovician boundary. The succession is mainly composed of carbonate rocks intercalated with some clastic sedimentary rocks bearing limestone lenses and yielding various fossils (Zeng et al., 1983; Wang et al., 1987). The structure is very simple with the strata gently dipping to the east. Many Ordovician specialists at home and abroad, including the delegation of the Ordovician Subcommittee, some colleagues attending the field excursion

during the Fourth International Graptolite Conference and 30th IGC as well as the Field Workshop Meeting of IUGS 410 project etc., have visited the section since 1978.

### Geological setting

Geographically this area is on the east limb of the Huangling Arch, and belongs to the north-central Yangtze carbonate platform (Figure 2). The Ordovician rocks, together with the underlying Cambrian and overlying Silurian deposits are widely distributed onion-skin-like around the Huangling Arch. Among them the Ordovician section at Huanghuachang and the Ordovician-Silurian boundary section at Wangjiawan, 22 km NE of the Huanghuachang are attracting attention for stratigraphic subdivision and correlation on a worldwide scale. In the section, strata dip at 11° to east. Otherwise, the section is structurally undeformed.

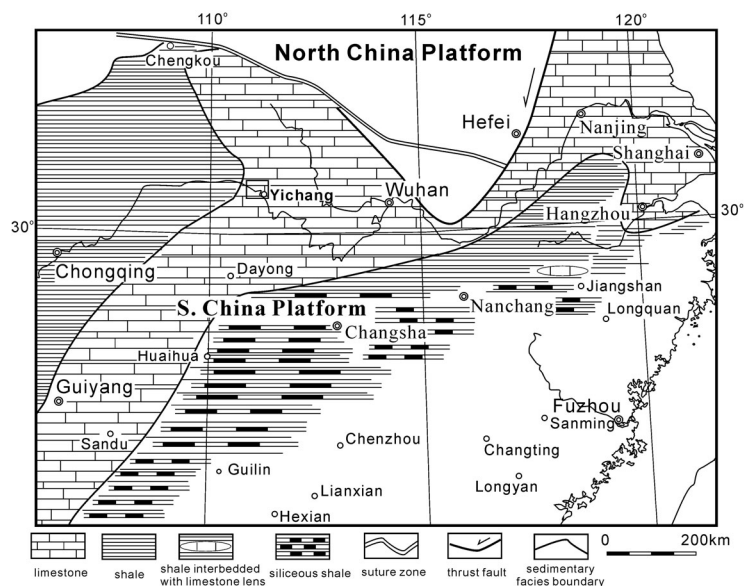


Figure 2 Lithofacies differentiation in the Central Yangtze Platform during the Ordovician Dawan Stage.

## Lithostratigraphic subdivision of the recommended GSSP

The Ordovician stratigraphic succession of the Yangtze Gorges area is subdivided into 10 formations shown in Figure 1. The Huanghuachang section with the Lower/Middle Ordovician boundary interval begins in the Honghuayuan Formation, which is a high-stand thick-bedded limestone with *Archaeocyphia*, *Calathium* and conodonts of the *Serratognathus diversus* Biozone in the lower-middle parts and conodonts of the *Oepikodus communis* Biozone in the uppermost part (Figure 3). The *Oepikodus communis* Biozone ranges into the overlying Dawan Formation.

The Dawan Formation was defined by Zhang (1962) on the basis of the Dawan Bed (Zhang et al., 1957) and the *Yangtzeella* Bed established by Lee (1924). Zeng et al. (1983) subdivided the Dawan Formation of the Huanghuachang section into three lithological units: the Lower Unit, the Middle Unit and the Upper Unit (Figures 1, 3) (Wang et al., 1987, 1995). The Lower Unit and the lower part of the Middle Unit comprise most of the Huanghuachang section and are described in Appendix and Figure 3. In addition, the Lower Unit is subdivided informally into lower, middle, and upper parts, which are terms used in the following description, the Appendix, and the figures. The symbols Hod and SHod, used in the text, the Appendix, and figures, refer to beds or thin stratigraphic intervals sampled for fossils.

The Lower Unit is 12.97 m thick, and composed of gray, thin-bedded and minor medium-bedded limestone, bioclastic limestone and glauconitic limestone with yellow-green shale interbeds (Figure 3, Appendix). The lower part of 5.45 m (Hod29–Hod4) comprises gray thick-bedded glauconitic limestone, 0.93 m thick (Hod29–Hod27), overlain by thin-bedded glauconitic limestone and nodular limestone with yellow green shale interbeds. The middle 4.52 m of the Lower Unit (Hod3–SHod11) is composed of gray thin-bedded limestone and bioclastic limestone with yellow-green shale interbeds overlain by 0.9 m of the light purple-gray medium-bedded dolomitic micritic limestone (SHod9–11). The upper part of the Lower Unit is 3m thick composed of light purple thin-bedded nodular limestone and medium-bedded limestone interbedded with yellow-green shale with limestone lenses (SHod12–24).

The proposed base of the Middle Ordovician Series, defined by the FAD of *Baltoniodus? triangularis*, is located at the base of the bed of SHod-16. This is 0.6 m above the top of the distinctive 0.9m-thick, medium-bedded dolomitic micritic limestone (SHod9–11) and 10.57 m above the base of the Dawan Formation. This level coincides with the first appearance of *Periodon* sp. A (sensu Bagnoli & Stouge, 1997) and is close to the FAD of *Microzarkodina flabellum*. The Lower Unit yields a mixed fauna of conodonts, trilobites, brachiopods, graptolites, chitinozoans and acritarchs, representing cool-water biota mixed with warm-water biota (Wang, 1980; Wang & Chen, 1999). Three conodont biozones, the

*Oepikodus communis* Biozone, *Oepikodus evae* Biozone (sensu Lindström, 1971; Bergström, 1995) and *Baltoniodus? triangularis*-*Microzarkodina flabellum* Biozone, can be recognized in the unit.

The Middle Unit of the Dawan Formation comprises 13 m of purple medium-bedded micrite with yellow-green mudstone and shale interbeds. The conodonts are referred to the *Baltoniodus navis* conodont Biozone, the cephalopods to the *Protocycloceras* Biozone, and brachiopods are common and include *Yangtzeella poloi*.

The 28 m thick Upper Unit of the Dawan Formation at Huanghuachang section consists of yellow-green shale intercalated with thin-bedded nodular limestone and mudstone. Graptolites of the *Undulograptus sinodontatus* Biozone occur at the base of the upper unit and representatives of the *U. austrodentatus* Biozone are present at the top. Here they occur together with trilobites of the *Hanchugolithus* Biozone, brachiopods of the *Euorthisina* Biozone and conodonts of the *Baltoniodus norrandicus* and *Lenodus anti-variabilis* Biozones (An, 1987; Wang, et al., 1987; Stouge, in prep.). Thus, the Upper Unit of the Dawan Formation correlates with the Yapeian and lowest Darriwilian.

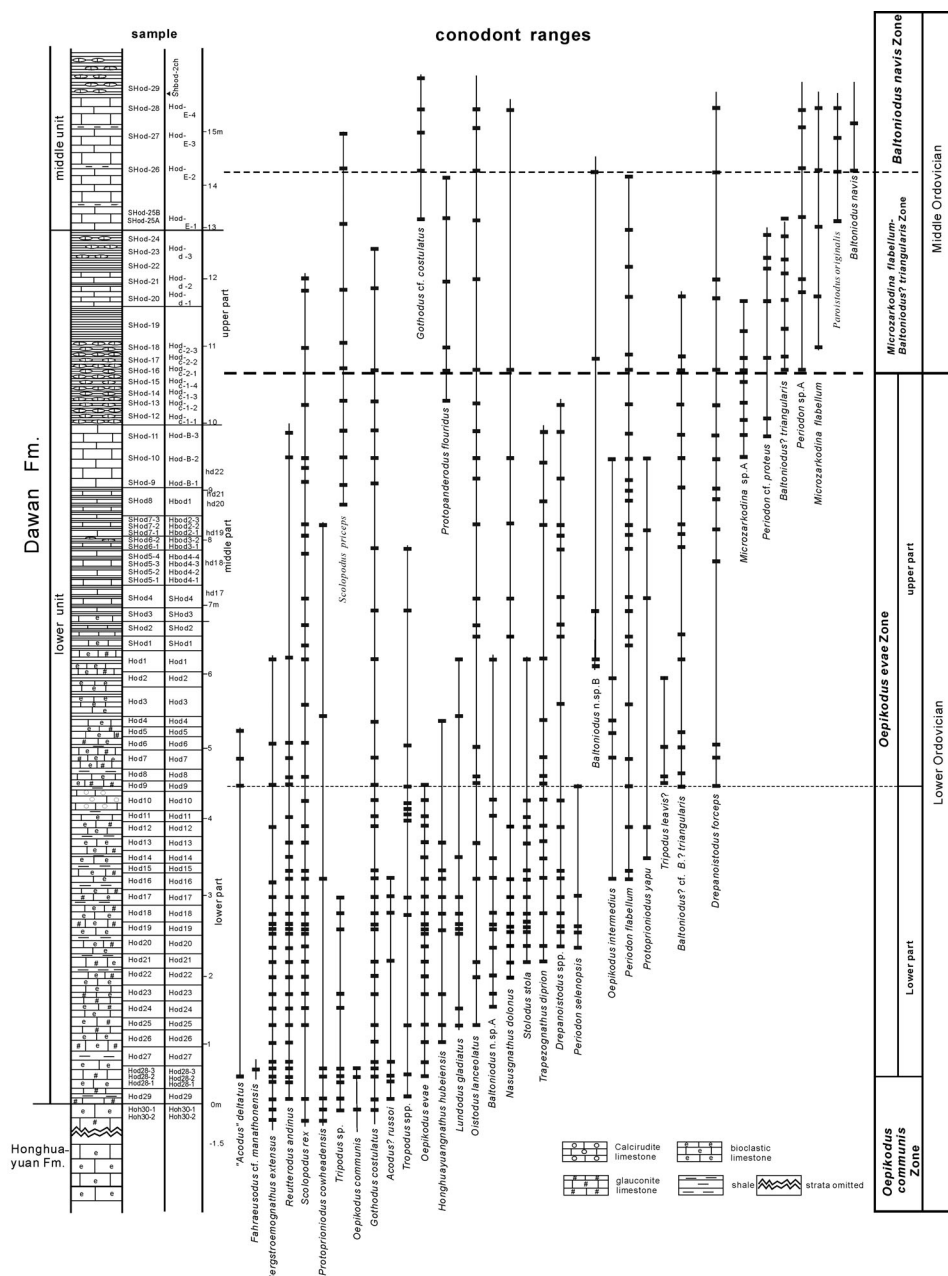


Figure 3 Stratigraphic ranges of selected conodonts and their sampled position of the Huanghuachang section.

The Dawan Formation is widely distributed on the Yangtze Platform (Figures 1, 2). In the Yichang area, there are at least two other relevant sections that have been studied, the Chenjiahe (i.e. Daping) section and the Jianyangping section (Figure 1). They are exposed, respectively, in the eastern and western limbs of the Huangling Arch, and correlation with the Huanghuachang section is straightforward. The Chenjiahe section is 5 km north from the Huanghuachang section. It is well exposed along a country roadside. The Jianyangping section is well exposed on the main roadside, close to a small town named Jianyangping in the Xinshan County. The conodonts of the Chenjiahe section have been studied in detail by Stouge (in prep.). The conodont, graptolite, and chitinozoan biostratigraphic successions and their relationship across the Lower and Middle Ordovician boundary interval at the Huanghuachang section are also documented in the Chenjiahe and Jianyangping sections (see Figures 3, 6, 7).

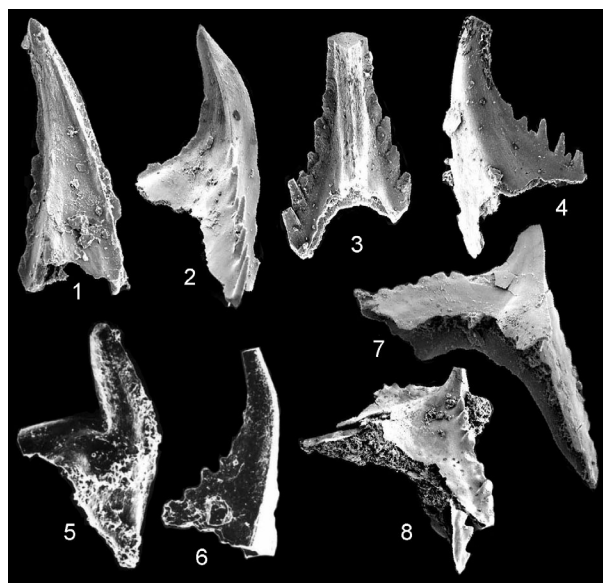
## Conodont biostratigraphy in Huanghuachang section

The conodonts from the Lower Unit of the Dawan Formation have been studied in detail by several specialists (Zeng, et al., 1983; An, 1987; Ni, in Wang et al., 1987; Wang, Z. et al., 1995; Wang & Bergström, 1998; Chen, X. et al., 1995; Stouge, in prep.). The conodont species association and succession from the lower Dawan Formation mark a prominent change from the underlying fauna of the Honghuayuan Formation, which includes taxa of the *Serratognathus diversus* and *Oepikodus communis* Biozones (An et al., 1987).

The *Oepikodus communis* Biozone spans about 1.73 m in the uppermost Honghuayuan Formation (Hod 31, Hod 30) and the 0.93 m-thick glauconitic bioclastic limestone (Hod 29, 28) at the base of the Dawan Formation. The base of the *Oepikodus communis* Biozone is defined by the FAD of the nominate species and the top is at the first appearance of the early type of *Oepikodus evae* (Hod 28-3).

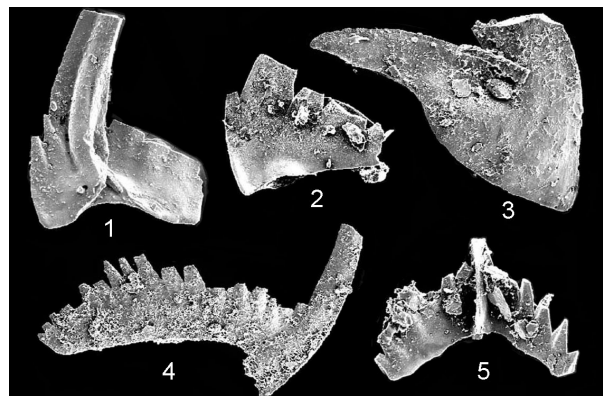
The *O. evae* Biozone can be recognized in the Lower Unit of the Dawan Formation (Wang et al., 1987, 1992a, b, 1996; Wang Z. et al., 1995; Chen et al., 1996) (Figure 3). As defined, the *O. evae* Biozone ranges from the FAD of *Oepikodus evae* to the FAD of the *Baltoniodus? triangularis*. *O. evae* first appears within the thick-bedded glauconitic bioclastic limestone (Hod 28-3), 0.6 m above the base of the Dawan Formation, and ranges upwards to the level of Hod 9, 4.35 m above the base of the Dawan Formation. *Oepikodus evae* is represented first by an early type succeeded by *Oepikodus intermedius*. Advanced *O. evae* specimens typical for the Baltic region and described by Lindström (1971) follow and represent *O. evae* Biozone (sensu stricto). Associated important conodont species include *Bergstroemognathus extensus*, *Gothodus costulatus*, *Juanognathus variabilis*, *Lundodus gladius*, *Periodon* spp., *Reutterodus andinus*, *Tropodus* spp. and a group of undescribed taxa belonging to Balagnathidae (e.g. *Baltoniodus* n. sp. A, B. n. sp. B, and *Baltoniodus tetrastichus* Li et Wang, sensu Wang et al., 2003a, b; Li et al., 2004). *Reutterodus andinus* is present throughout the biozone.

The upper part of the *O. evae* Biozone is without the nominated species and the interval between Hod 9 and SHod 15 is characterized by *Trapezognathus diprion*, *Periodon flabellum*, *Gothodus* sp., *Tropodus* sp., *Drepanoistodus forceps*, *Oepikodus intermedius*, *Periodon selenopsis*, *Baltoniodus? cf. B.? triangularis*, *Tripodus laevis?*, *Gothodus* sp., *Protoprioniodus yapu* and *Microzarkodina* sp. A. The last species occurs in the uppermost part of the biozone. The conodont association and succession of the upper *O. evae* Biozone (Figure 3) are similar to those of the *Trapezognathus diprion* and *Microzarkodina* sp. interval Zones which was reported from Öland, Sweden (Stouge et al., 1995; Bagnoli & Stouge, 1997). In the Huanghuachang section the first *Oepikodus intermedius* occurs in bed of Hod 16 with *Periodon flabellum* (3.03 m above the base of the Dawan Formation), a bit higher than the first occurrence of *Stolodus*



**Figure 4** *Baltoniodus? triangularis* (Lindström)  
1) Sd element, posterior-lateral view, x150, no. Hod-c-2-3/5936, hor. SHod-18.  
2) Pa element, lateral view, x150, no. Hod-c-2/6009, hor. SHod-16.  
3) Sa element, posterior view, x180, no. Hod-c-2/5999, hor. SHod-16.  
4) Sc element, lateral view, x180, no. Hod-c-2/6000, hor. SHod-17.  
5) M element, lateral view, x120, no. SHod-16/1467, hor. SHod-16.  
6) Sb element, lateral view, x120, no. SHod-16/1468, hor. SHod-16.  
7) Pb element, lateral view, x120, no. Hod-c-2/6007, hor. SHod-17.  
8) Pb element, lateral view, x90, no. Jod-23/6053, hor. Jod-23.

*stola* and *Trapezognathus diprion* in Hod 19, and ranges up to the upper part of the *O. evae* Biozone. The base of the upper *O. evae* Biozone herein is indicated by the first *Drepanoistodus forceps*, *Baltoniodus? cf. B.? triangularis* and *Tripodus cf. laevis* at the base of Hod 9. The former is a very common species reported from the *O. evae* to *B. navis* Zone in Baltic region (Rasmussen, 2001) and NW Russia (Tolmacheva & Fedrov, 2001). *Baltoniodus? cf. triangularis*, which was identified as *Baltoniodus triangularis* (sensu An, 1987; Ni, in Wang, et al., 1987; Wang et al., 2003a, b; Li et al., 2004, Pl.2, figs.7–12), is similar to typical *B.? triangularis* (Lindström) from the Baltic region in most aspects, but the main difference is the lack of confluent denticles on the anterior process of the Pb element. It is also similar to *Trapezognathus diprion*, but differs from the latter in the development of free denticles on the anterior and posterior processes of the P element. Thus, the species *Baltoniodus? cf. B.? triangularis* is here proposed as an intermediary form in a phyloge-



**Figure 5** *Microzarkodina flabellum* (Lindström)  
1) Sd element, lateral view, x150, no. Hd-37/5905, hor. SHod29.  
2) P element, lateral view, x180, no. Hod-c-2-3/5952, hor. SHod-18.  
3) M element, lateral view, x150, no. Hd-37/5918, hor. SHod29.  
4) Sc element, lateral view, x90, no. Hd-31/5927, hor. SHod-26.  
5) Sa element, posterior view, x180, no. Hod-c-2-3/5948, hor. SHod-18.



The *Baltoniodus navis* Biozone is defined at the base of SHod 26, 1.5 m above the base of the Middle Unit of the Dawan Formation. It is characterized by the first appearance of *Baltoniodus navis* with *Periodon* sp. A, *Oistodus lanceolatus*, and *Paroistodus originalis*. This faunal association continues into the upper part of the Middle Unit. The following faunal succession is mainly composed of *Oistodus*, *Periodon* and *Paroistodus*. It is worth noting that *Paroistodus originalis* appears before *Baltoniodus navis* and ranges up to the middle Dawan Formation.

The FAD of *Baltoniodus? triangularis* is proposed as the boundary biomarker for the base of the Middle Ordovician. The evolving lineages of *Trapezognathus*, *Baltoniodus*, *Microzarkodina* and *Periodon* occur across the boundary and are good proxies for the boundary level (Figure 6).

In the Chenjiahe section the same conodont assemblages mentioned above are found across the suggested boundary (Figure 7).

### Graptolite biostratigraphy of the Huanghuachang section

Two graptolite zones, the *Corymbograptus deflexus* and *Azygograptus suecicus* Zones, were reported in the Lower Unit of the Dawan Formation of the Huanghuachang section by Wang et al. (1987, 1992a, 1995). Recently, *Didymograptellus bifidus* was discovered in the original *Corymbograptus deflexus* Zone and occurs earlier than *C. deflexus* in the Huanghuachang section (Figure 8). This species is found in four interbeds of yellow-green shale (Hod-22, Hod 18, Hod 8 and Hod 4) in the lower to middle parts of the Lower Unit. The lower two shale interbeds (Hod 22, Hod 18) occur between thin-bedded limestones with the conodonts *Trapezognathus diprion*, *Stolodus stola*, *P. selenopsis* and *Baltoniodus? n. sp. A* of the lower *O. evae* Biozone. The upper shale interbeds, 0.15 m thick (Hod 4), have *D. bifidus* with *C. deflexus*, *Tetragraptus bigsbyi* and *Acrograptus kurki* (Figure 8), and directly underlie the bed (Hod 3) with the first appearance of *Azygograptus suecicus*. Thus, the *D. deflexus* Zone is abandoned and replaced by the *D. bifidus* Biozone. The conodonts from the underlying and overlying limestones indicate that the boundary between the *D. bifidus* and *A. suecicus* Biozones is within the lower part of the upper *O. evae* Biozone (Figure 8).

The *Azygograptus suecicus* Biozone here is defined by the first appearance of the index fossil at the base of Hod 3, 5.45 m above the base of the Dawan Formation, and it ranges upwards to the lower part of the Middle Unit of the Dawan Formation. It may be subdivided into two intervals based on the species association of *Azygograptus*. The lower interval, located between the bed of Hod 3 and the bed of SHod 14, yields *Azygograptus suecicus*, *A. eivionicus*, and *Phyllograptus anna*, and the upper interval (SHod 15–29) *Azygograptus ellesi*, *A. suecicus*, horizontal *Xiphograptus svalbardensis* and *Tetragraptus* sp. Associated conodonts in the section indicate correlation of the lower *A. suecicus* Biozone with the major part of the upper *O. evae* conodont Biozone. The upper interval of the *A. suecicus* Biozone (SHod 15–SHod 29) occurs in the uppermost Lower Unit to the lower Middle Unit of the Dawan Formation and roughly corresponds to the *B.? triangularis* – *M. flabellum* to the lower *Baltoniodus navis* Biozones. The interval is without *A. eivionicus*, and it is characterized by *Azygograptus suecicus*, *A. ellesi*, *Expansograptus*, declined *Xiphograptus svalbardensis* and *Pseudotrionograptus* sp. in the lowest part (SHod 15–22).

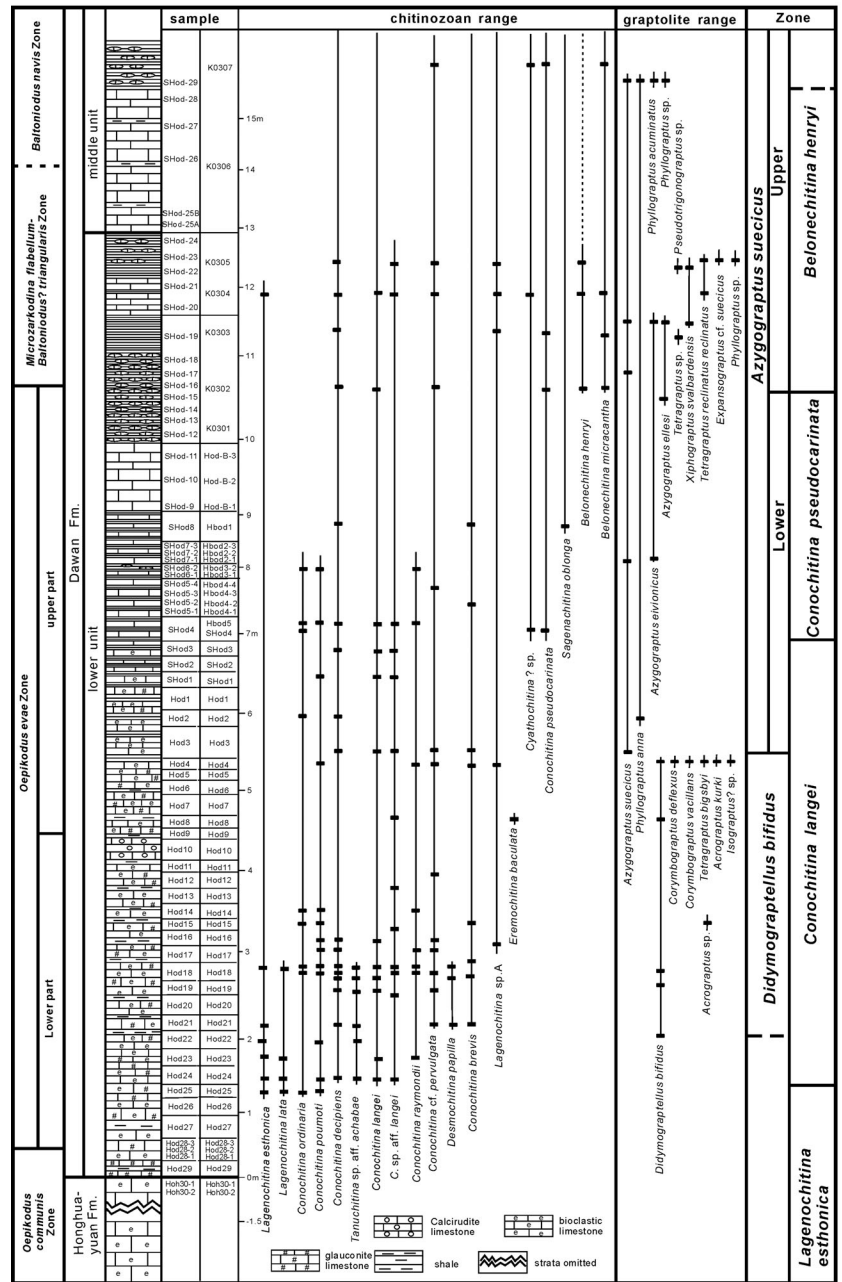


Figure 8 Stratigraphic ranges of major graptolites and chitinozoans and their sampled position in the Lower Dawan Formation of the Huanghuachang section.

The graptolite succession documented in the Lower Unit of the Dawan Formation with a continuous conodont succession offers a useful tie between the conodont and graptolite biozones worldwide. The *Didymograptellus bifidus* Biozone herein is suggested to correspond to the *D. "protobifidus"* and the *C. deflexus* Zones in the Jiangnan slope, South China (Zhang & Chen, 2003), the Australian "protobifidus" and *I. primulus* Zones (Webby & Nicoll, 1989; Cooper & Lindholm, 1991), and the North American *bifidus* Zone (Berry, 1960; Finney & Ethington, 1992). It is correlated with the upper *varicosus* to lower *simulans* Zones of Britain (Cooper et al., 1995) and the upper *balticus* to *densus* Zones of Baltoscandia on the basis of the presence of *D. bifidus* and *C. deflexus* (Figure 9). The overlying *Azygograptus suecicus* Biozone is widely recorded in the interval between the *D. bifidus* and *E. hirundo* Biozones in the Yangtze platform and between the *deflexus* and *I. caduceus imitatus* Biozones in the Jiangnan slope of South China plate (Chen et al., 2003; Zhang & Chen, 2003). *Azygograptus* is considered to be diagnostic of the *Isograptus-Azygograptus* radiation (Chen & Bergström,

1995) and one of the most characteristic genera of the Atlantic Province during the "Arenig" (Beckly & Maletz, 1991). It is widely reported from Britain, Scandinavia, Bohemia, northern Spain, Gorny Altai and southern Bolivia and South China (Beckly & Maletz, 1991; Cooper & Lindholm, 1990). Typical *Azygograptus suecicus* is documented in the uppermost part of the Töyen Shale, Scania, where it occurs together with *Expansograptus hirundo* and *Isograptus gibberulus*. The allied species of the genus is also reported from the *simulans* Zone with *I. cf. victoriae primulus* in Wales (Cooper et al., 1995) and from the *elongatus* Zone in Scandinavia (Cooper & Lindholm, 1990; Beckly & Maletz, 1991). The *A. suecicus* Biozone of the Huanghuachang section lies directly above the *D. bifidus* Biozone and below the upper Middle Dawan Formation. The latter is overlain by the *U. sinodentatus* Biozone at the base of the Upper Dawan Formation. This suggests that the *A. suecicus* Biozone here is coeval with the *lunatus* to *victoriae* Biozones of Australia (Webby & Nicoll, 1989), North America (Berry, 1960) and Canada (Williams & Stevens, 1988), and approximately equivalent to the Scandinavian *elongatus* to lowest *hirundo* Biozones, and the British upper *simulans* Zone to the lower *gibberulus* Zone (Cooper et al., 1995). The upper Middle Dawan Formation, located between the *A. suecicus* and *U. sinodentatus* Biozones in the Huanghuachang section, should correspond to Ca 3-Ca 4 of the Australian standard. It is important to note that the typical *Azygograptus ellesi* was found in the *elongatus* Zone near Oslo, Norway together with *I. v. cf. lunatus* (Maletz, 1992). This species in the Huanghuachang section, however, appears in the lowest part of the upper *A. suecicus* Biozone (SHod 15) and just below the level with FAD of *B. ? triangularis* (SHod 16). The succeeding horizontal *Xiphograptus svalbardensis*, its declined form, and *Pseudotrigraptus* are common in the *lunatus* and *victoriae* Zones in the Cow Head Group of Western Newfoundland, Canada (Williams & Stevens, 1988). These indicate that the *elongatus* Zone is equivalent to the *lunatus* Zone, while the boundary between the *lunatus* and *victoriae* Biozones in these localities mentioned above is nearly coincident with the boundary between the lower and upper *A. suecicus* Biozones and close to the base of the *Baltoniodus? triangularis-Microzarkodina flabellum* Biozone (SHod 16) in the Huanghuachang section (Figure 9). This correlation is also suggested by the conodont graphic correlation (Stouge et al., 2005).

mation covers the interval of the *D. bifidus* to the lower part of the *A. suecicus* Biozone or the lower to lower upper *O. evae* conodont Biozone (Figure 8). The principal chitinozoans include *Lagenochitina esthonica*, *Conochitina brevis*, *C. decipiens*, *C. poumoti*, *C. ordinaria*, *C. langei*, *Tanuchitina* sp. aff. *achabae* and *Eremochitina baculata*. Although the last species is considered as a diagnostic for northern Gondwana (Paris, 1990), the chitinozoan assemblage is similar to that of the *C. langei* / *C. brevis* Zone reported from the Lévis Formation, Canada (Achab, 1986, 1989). The *C. langei* Biozone at Huanghuachang is correlative only with the lower part of the *C. langei*/*C. brevis* Zone based on associated graptolites and conodonts.

The overlying *Conochitina pseudocarinata* Biozone is defined by the FAD of the nominated fossil at the bed of SHod 4. Most of the associated chitinozoans ranging into the zone from below, except *Sagenachitina oblonga* and *Cyathochitina? sp. C. pseudocarinata* and *S. oblonga* which first appear in the biozone, are considered to be representative of the *D. ornensis* Biozone in north Gondwana (Paris, 1990, 1996). The *C. pseudocarinata* Biozone at Huanghuachang, therefore, is correlated with the *D. ornensis* Biozone in north Gondwana. The upper limit of the *C. pseudocarinata* Biozone is defined by the first appearance of *Belonechitina henryi* at the bed of SHod 16.

The *B. henryi* Biozone is characterized by the first appearance and development of the nominated fossil together with *B. micracantha* and *Conochitina kryos*. This chitinozoan association indicates that the *B. henryi* Biozone of the section is equivalent to the *Belonechitina henryi* Biozone in north Gondwana (Paris, 1990, 1996). In the Huanghuachang section, the base of the *B. henryi* Biozone is very close to or coincident with the base of *B. ? triangularis-M. flabellum* conodont Biozone.

Well-preserved and diversified acritarchs have been reported from the Lower Dawan Formation by Brock & Li (1999), Yin et al. (1998), and Li et al. (2002). The latest study indicates the correlation of the *Arbusculidium filamentosum-Aureoestea clatirata* Assemblage Zone with *Didymograptellus bifidus* Biozone and the overlying *Ampullula-Barakella felix* Assemblage Zone (Li et al., 2002) with the *Azygograptus suecicus* Biozone.

The graptolite, chitinozoan and acritarch assemblages in the lower Dawan Formation indicate that the proposed boundary biohorizon for the Middle Ordovician Series is close to the base of the upper *Azygograptus suecicus* graptolite Biozone and within the *Ampullula-Barakella felix* acritarch Assemblage Zone. It is nearly

## The chitinozoans and acritarchs of the Huanghuachang section

The chitinozoans in the Dawan Formation were reported by Chen et al. (1996, 2002). Further sampling has shown that four chitinozoan biozones can be recognized in the Lower and lower Middle Units of the Dawan Formation.

The *Lagenochitina esthonica* Biozone is defined by the incoming of the index fossil in lowest *O. evae* Biozone. This species, however, is widely recorded from the lowest Dawan Formation and correlative strata throughout the Yangtze platform with *Conochitina raymondii*, *C. ordinaria*, and these represent the primary radiation of the chitinozoan fauna during the Early Ordovician (Wang & Chen, 2003). The *L. esthonica* Biozone herein indicates correlation with the *L. esthonica-Conochitina raymondii* Zone reported from Quebec and western Newfoundland, Canada (Achab, 1989) based on the co-occurrence of nominated species below the first appearance of *Conochitina langei*.

The overlying *Conochitina langei* Biozone is defined by the FAD of the index fossil at bed Hod 24 and extends upwards to the FAD of *Conochitina pseudocarinata* at the bed of SHod 4. The chitinozoan biozone in the Lower Unit of the Dawan For-

		South China		Baltoscandian	N. American	W. Newfoundland, Canada	Britain	Australasia	
		Huanghuachang section graptolite	Jiangnan Slope conodont						
Middle Ordovician	Middle Unit	suecicus	<i>B. navis</i>	caduceus imitatus	hirundo (lower part)	victoriae	victoriae	gibberulus (lower part)	Ca2 victoriae
	Upper		<i>B. ? triangularis/M. flabellum</i>						
Lower Ordovician	Dawan Formation	Lower Unit	Upper	suecicus	elongatus	lunatus	lunatus	simulans	Ca1 lunatus
	Lower Unit								Lower
		Lower	O. communis	"protobifidus"	balticus	fruticosus	fruticosus	fruticosus	
				Lower					O. communis
	no graptolite		approximatus		phyllo-graptoides	approximatus	approximatus	phyllo-graptoides	

Figure 9 Correlation of the graptolite biozones across the Lower/Middle Ordovician boundary between the Huanghuachang section with the Jiangnan slope, South China (Zhang & Chen, 2003), North America (Berry, 1960; Finney & Ethington, 1992), Australia (Webby & Nicoll, 1989; Cooper & Lindholm, 1991), Canada (Williams & Stevens, 1988), Baltoscandia and Britain (Cooper et al., 1995).

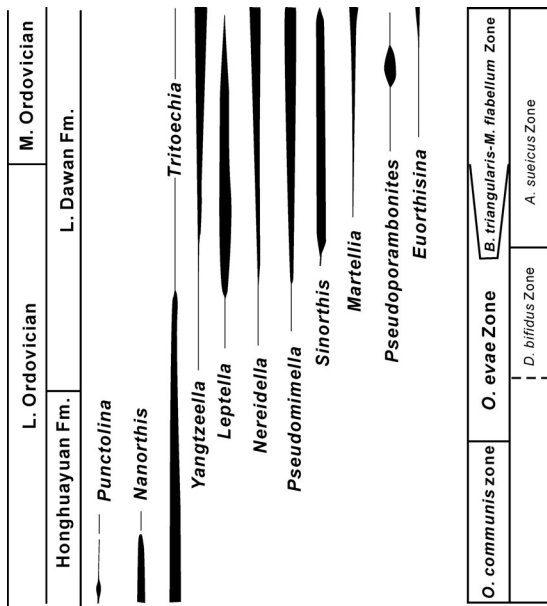


Figure 10 Stratigraphic range of major brachiopods from the Lower Dawan Formation of the Huanghuachang section.

coincident with the base of the *Belonechitina henryi* chitinozoan Biozone (Figure 8).

### Other invertebrates

Brachiopods are common in the Lower Unit of the Dawan Formation and were studied in detail by Zeng et al. (1983). The *Leptella* and *Euorthisina* brachiopod Biozones are recognized in the Lower Unit. The common brachiopods include *Leptella*, *Sinorthis*, *Pseudomimella*, *Tritoechia*, *Noreidella*, *Pseudoporambonites*, *Euorthisina*, *Yangtzeella*, *Martellia*, *Eremotochia* and *Lepidorthis* (Figure 10). The *Leptella* Biozone is characterized by the appearance of the index fossil at the base of the Dawan Formation. Its upper limit is defined by the appearance of *Euorthisina*, although *Leptella* itself may extend upwards to the uppermost part of the Lower Unit. The *Euorthisina* Biozone is indicated by the presence of the zonal fossil with *Pseudoporambonites*, *Euorthisina* and *Lepidorthis*. Associated graptolites indicate the correlation of *Leptella* Biozone with the *D. bifidus* Biozone to the lower interval of the *A. suecicus* Biozone. The overlying *Euorthisina* Biozone corresponds to the upper interval of the *A. suecicus* Biozone and extends upwards to the *U. austrodentatus* Biozone.

Trilobites from the Lower Unit of the Dawan Formation were reported by Zhou (in Wang et al., 1987). The principal trilobites include *Pseudocalymene*, *Carolinites*, *Phorocephala*, *Liomegalaspides*, *Amphyx*, *Ovalocephalus*, *Pseudobasilicus* and *Taihuangshania* (Figure 11). Most of them have a long range, except for the first three genera that are mainly found in the Lower Unit of the Dawan Formation. Hence, *Pseudocalymene cylindrica* was selected as the zonal fossil for the Lower Unit (Zhou, in Wang et al., 1987). *Carolinites genacenaca*, which has been reported from the *Reutterodus andinus* Zone in North America (Ross et al., 1997), is found in the lower part of the Lower Dawan Formation.

### Organic maturity

The organic maturity of the Huanghuachang section was studied using CAI, reflectance of graptolites and chitinozoans, and IR-studies (Wang et al., 1992b, 1993). The vitrinite reflectance equivalent is estimated 0.9–1.1 % Ro, and the CAI is 2–3, indicating that the Huanghuachang section is suitable for the palaeomagnetic and geochemical studies.

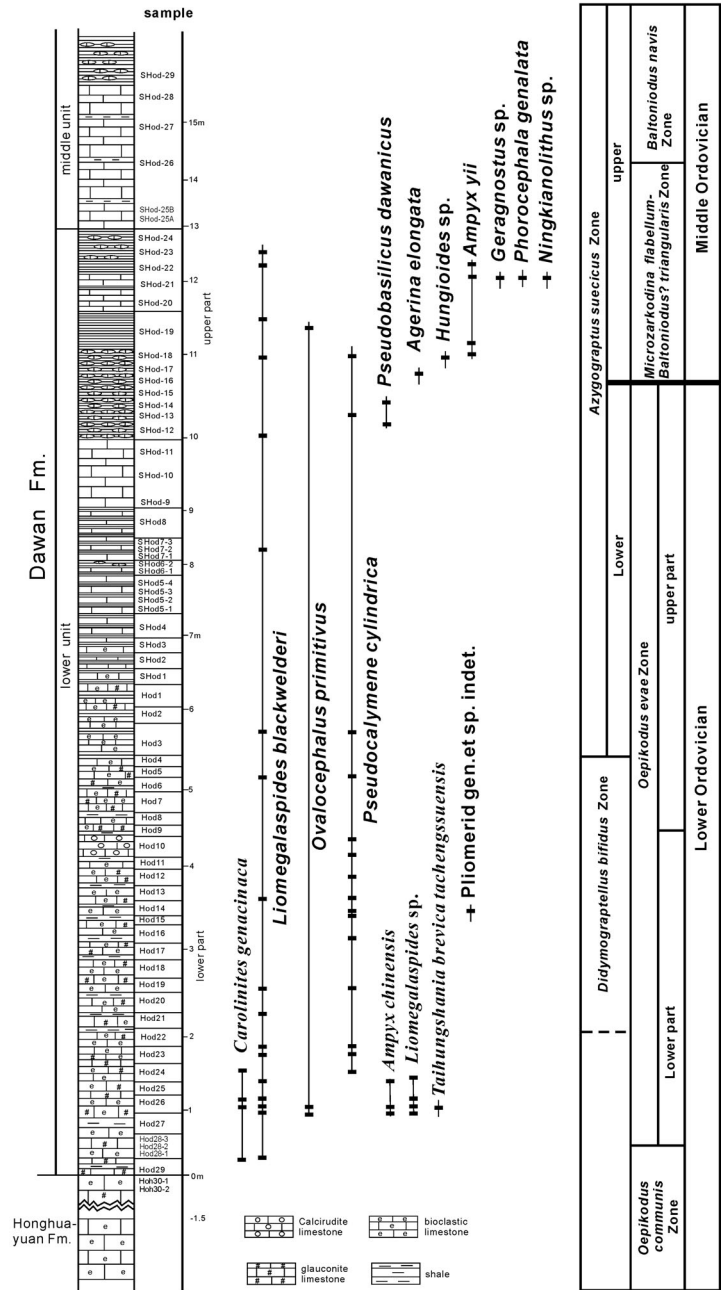


Figure 11 Stratigraphic range of major trilobites from the Lower Dawan Formation of the Huanghuachang section.

### Sequence stratigraphy of the Dawan Formation

The study of sequence stratigraphy facilitates the subdivision of the Lower Dawan Formation into three transgressive to regressive cycles or sequences (Figure 12). The first and second cycles, showing a generally transgressive trend and deepening upwards (Wang et al., 1995), occupy the lower-middle parts of the Lower Unit. Brachiopods indicate the BA1-2 brachiopod community (Zeng et al., 1991). An obvious change in lithofacies and sequence first appears between the glauconitic bioclastic limestone of 0.93 m with rich conodonts and brachiopods at the base of the Dawan Formation (Hod29-27) and the underlying thick-bedded dolomitic limestone (Hod30-31) with *Archaeocyphia*, *Calathium* at the top of the Honghuayuan Formation. This sequence turnover was associated with the replacement of warm water biota by the cool-water mixed with warm-water biota (Figure 12). The second cycle covered the middle part of the



Lower Unit, and contained brachiopods of BA2-3 community (Zeng et al., 1991). It starts at the base of yellow-green shale interbeds (Hod 3) with first appearance of *Azygograptus suecicus*. The underlying highstand regressive thin-bedded bioclastic limestone yields numerous brachiopods. The second cycle was characterized by a smaller sea-level rise succeeded by a gentle regression and terminated at the top of the 0.9 m-thick, highstand dolomitic limestone in the uppermost middle part of the Lower Unit with the first appearance of *Microzarkodina* sp. (SHod 9–11). The lowstand deposit of the third sequence, marking the base of the upper part of the Lower Unit, is considered to represent an important worldwide sea-level lowstand event in the Lower/Middle Ordovician boundary interval (Ross & Ross, 1992; Nielsen, 1992). In the Huanghuachang section this event is recognized by sequence change. The succeeding transgressive deposits, covering the interval from the uppermost *Oepikodus evae* Biozone to the lowest *Baltoniodus? triangularis-Microzarkodina flabellum* Biozone (SHod12–18), are characterized by thin-bedded nodular limestone with yellow-green shale interbeds, bearing *Baltoniodus? triangularis*, *Periodon* sp.A and minor *Azygograptus suecicus*, and *A. ellesi*. The transgressive peak is here

interpreted to correspond with 0.5 m of yellow-green shale with graptolites in the lower part of the upper interval of the *Azygograptus suecicus* Biozone (SHod 19) (Figure 12). A small regression (SHod 20–21), in turn succeeded by a gentle sea-level rise, is interpreted for the upper part of the upper *A. suecicus* Biozone, and it extends up to the uppermost part of the Lower Unit (SHod22–24). The purple medium-bedded limestone of the Middle Unit represents the highstand regressive deposits. A smaller sea-level rise is coincident with the last appearance of *Azygograptus suecicus* in the middle of the Middle Dawan Formation. The Upper Unit of Dawan Formation has a transgressive succession, deepening and fining upwards. A sequence change is recognized at a level between the Middle and Upper Units of the Dawan Formation and supported by a change in the brachiopod communities from BA 2-3 in the Middle Unit to BA 4 in the Upper Unit (Zeng, 1991).

### Stable isotopic record

During the Early-Middle Ordovician, the Yangtze platform was covered by an epicontinental sea with predominantly carbonate deposition. The Huanghuachang section, located in the north-central shallow to middle-shelf area of the basin, has a continuous Lower to Middle Ordovician sequence dominated by carbonates with minor argillaceous deposits. The carbon isotopic data obtained from whole rock samples are analyzed by the MAT 251 mass spectrometer in the Isotopic Geochemistry Laboratory of Yichang Institute of Geology & Mineral Resources. The result shows in general a steady rising trend during most of the *O. evae* Biozone (Figure 12). The  $\delta^{13}C$  curve begins with a low excursion of around 0‰ in the lowest Dawan Formation and then follows a steady rise of  $\delta^{13}C$  values until the maximum value of +0.68 ‰ close to the boundary between the middle and upper parts of the Lower Dawan Formation. Higher in the section, the  $\delta^{13}C$  values are constant, but define two small peaks in the upper part of the Lower Unit to the lower part of the Middle Unit. The isotopic composition of the lower Dawan Formation reveals a significant relation of positive isotopic shifts with biotic diversification and sea-level fluctuation. The lowest  $\delta^{13}C$  value is found to be associated with the transgressive facies at the base of the Dawan Formation and the related biotic change. The warm water biota was replaced by a predominately cool-water biota. The two succeeding positive excursions (Nos. 2, 3) (Figure 12) during the first transgressive to regressive cycle may reflect changes in carbonate sedimentation and organic productivity. A relatively higher  $\delta^{13}C$  value (No. 4) is coincident with the sea-level fall preceding the FAD of *Azygograptus suecicus*. An interesting change is the maximum carbon isotopic positive excursion (No. 7), which is coincident with a sea-level lowstand and an accumulation of various organically shelly fossils at the Huanghuachang section. This is interpreted to be related to the eustatic sea-level lowstand event found in the lowest Whiterockian of North America (Ross & Ross, 1992) and the lowest Volkhov of Baltoscandia (Nielsen, 1992). It is worth noting that this event in the continuous sedimentary succession of the Huanghuachang section was preceded by the biological evolutionary event represented by the FAD of *B.? triangularis*. Further up section are two smaller positive isotopic excursions (Nos. 8, 9), which may be related

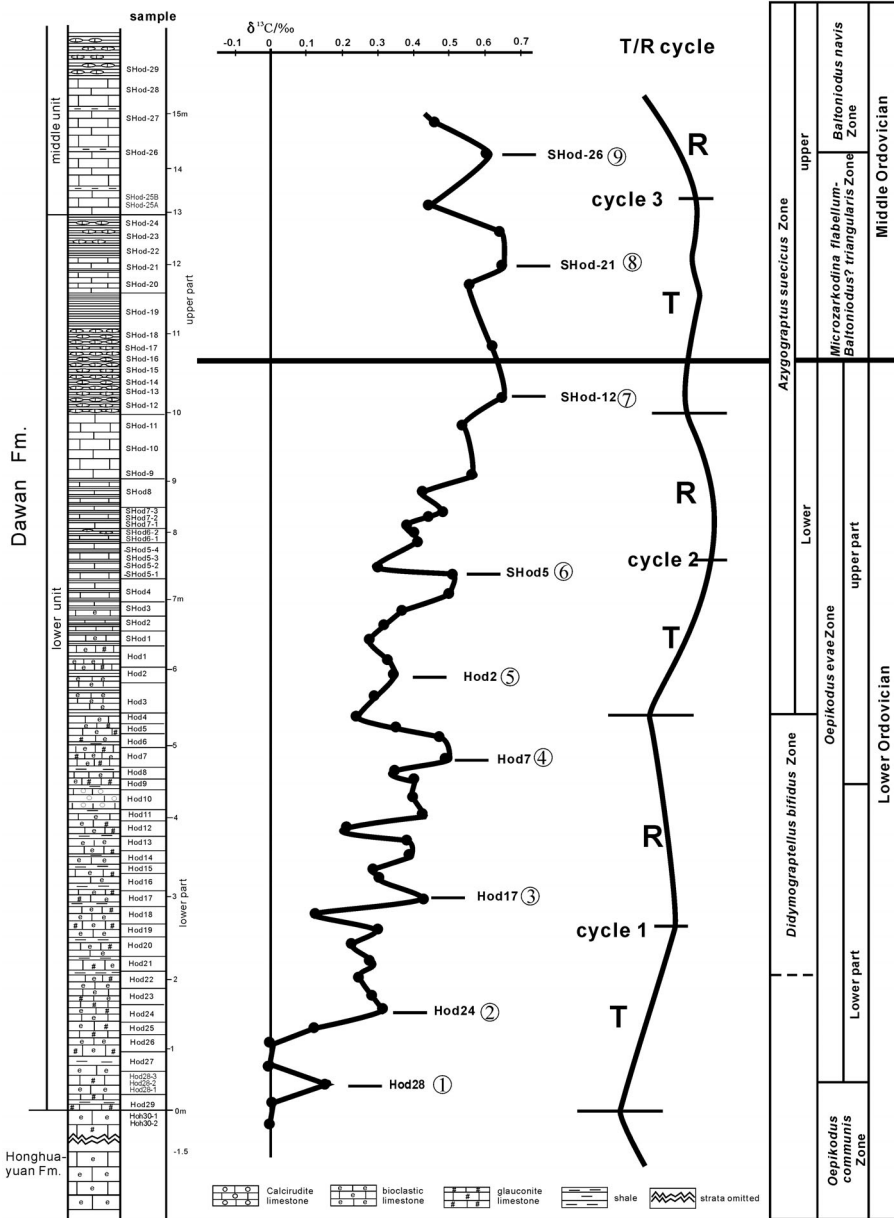


Figure 12  $\delta^{13}C$  data on the carbonates from the Lower Dawan Formation and their relation with sea-level changes in the Huanghuachang section.



**Figure 13** The Huanghuachang Lower/Middle Ordovician boundary section. The level with FAD of *B.?* *triangulates* is located at the base of SHod-16 (indicated by the stone marker), 0.6m above the grayish purple medium limestone and 10.57 m above the base of the Dawan Formation.

to changes in carbonate sedimentation and produced by the smaller sea-level pulses.

## Selection and correlation of boundary biohorizon and point

### Selection and definition of boundary biohorizon and point

The conodont succession identified in the lower Dawan Formation of the Huanghuachang section has the best potential for correlation and definition of the global Lower/Middle Ordovician Series boundary. Several conodont biohorizons with continuous lineages (Figures 3, 6) could be proposed for the definition of the base of global Middle Ordovician Series, e.g. the FAD of *Oepikodus intermedius/Periodon flabellum* at the bed of SHod16, the FAD of the *Microzarkodina* sp. A at the bed of SHod10 and the FAD of *Baltoniodus? triangularis/Microzarkodina flabellum* at the bases of SHod 16/SHod 18 in the Lower Dawan Formation.

After careful consideration assessment of these biohorizons for global correlation, the FAD of *Baltoniodus? triangularis* is proposed as the biohorizon defining the base of the Middle Ordovician Series in the Huanghuachang section. This datum is followed by the FAD of *Microzarkodina flabellum*, which is very useful for global correlation of the boundary. The proposed biohorizon at the Huanghuachang section approximates the boundary between the lower and upper *Azygograptus suecicus* Biozones. It is nearly coincident with the base of the *Belonechitina henryi* chitinozoan Biozone, and 0.6 m above the level with the maximum carbon isotopic excursion related with the worldwide lowstand event.

### Identification of the boundary biohorizon and point in field

The boundary biohorizon (or point) is located in a roadside exposure at the base of the bed SHod-16. This level, biostratigraphically, is 0.2 m below the FAD of *Microzarkodina flabellum*, close to the boundary between the lower and upper *Azygograptus suecicus* Biozones and nearly coincides with the base of the *Belonechitina henryi* chitinozoan Biozone. Lithostratigraphically this level is 10.57 m above the base of the Dawan Formation and 0.6 m above the top of the distinctive 0.9 m thick, highstand dolomitic limestone (SHod-11) in the uppermost middle part of the Lower Unit of the Dawan Formation. The boundary biohorizon or point falls within a transgressive succession characterized by thin-bedded nodular limestones with graptolite-bearing yellow green shale interbeds (Figure 13).

Its geographic coordinates are: latitude 30°51'37.8"N; longitude 110°22'26.5" E of Greenwich.

### Global correlation of the recommended GSSP

The base of the *B.?* *triangularis* Zone in Baltoscandia was suggested to coincide with the base of *Tripodus laevis* Zone in North America based on considerable available evidence (Bergström 1995). Both were proposed as the biohorizon for the definition of the base of the global Middle Ordovician Series (Webby, 1994, 1995). The conodont succession identified in the lower Dawan Formation of the Huanghuachang section further demonstrates that the base of the *B.?* *triangularis-Microzarkodina flabellum* Biozone can easily be recognized in both the North Atlantic Realm and the Mid-Continent Realm (Figure 14). The recommended biohorizon coincides with the base of the *T. laevis-M. flabellum* interval in type localities for the North American Whiterockian and the Ibxian sections (Ethington & Clark, 1982, Ross et al., 1995, 1997). It also correlates with the base of the *T. laevis* Biozone in the upper San Juan Limestone of Precordillera, San Juan, Argentina (Albanesi, 1999, 2003) based on the presence of diagnostic fossils typical of the underlying *Oepikodus evae* Biozone, e.g. *Reutterodus andinus*, *Oepikodus intermedius* and *Microzarkodina* sp. A. The conodont succession across Lower-Middle Ordovician boundary in Huanghuachang section indicates that the base of the *B.?* *triangularis* Zone with *Azygograptus* sp. in lowest Volkhov Stage of the Baltoscadian region (Bagnoli &

		Huanghuachang section			Jiangnan Slope South China	Balto-scandian	N. American	W. Newfoundland	Argentina	NW. Russia	Australasia
		conodont	graptolite	chitinozoa							
Middle Ordovician	Middle Unit	<i>B. navis</i>				<i>B. navis</i>	<i>altifrons</i>		<i>navis</i>	<i>navis</i>	Ca2 <i>victoriae</i>
	Dawan Formation	<i>B.?</i> <i>triangularis/M. flabellum</i>	<i>suecicus</i>	<i>henryi</i>	<i>I. caduceus imitatus</i>	<i>M. flabellum-B.?</i> <i>triangularis</i>	<i>flabellum-laevis</i>		<i>laevis</i>	<i>B.?</i> <i>triangularis</i>	
Lower Ordovician	Lower Unit	<i>O. evae</i>		<i>pseudo-carinata</i>	<i>suecicus</i>	<i>M. sp. A</i>		not zoned		<i>Microzarkodina</i> sp. A	Ca1 <i>lunatus</i>
	Upper				<i>deflexus</i>	<i>O. evae</i>	<i>T. diprion</i>	<i>leavis?</i>	<i>intermedius</i>		Ch2 <i>primulus</i>
	Lower		<i>bifidus</i>	<i>langei</i>	<i>protobifidus</i>	<i>O. evae</i>	<i>andinus</i>				Ch1 <i>protobifidus</i>
	Lower				<i>fruticosus</i>	<i>O. evae</i>		<i>evae</i>	<i>O. evae</i>	<i>O. evae</i>	Be1-4 <i>fruticosus</i>
	Honghuayuan Fm.	<i>O. communis</i>	no graptolite	<i>esthonica</i> <i>symmetrica</i>	<i>approximatus</i>	<i>P. elegans</i>	<i>O. communis</i>	<i>elegans</i>	<i>elegans</i>		La3 <i>approximatus</i>

**Figure 14** Biostratigraphic correlation across the Lower/Middle Ordovician boundary between the recommended GSSP with the Jiangnan Slope, China (Zhang & Chen, 2003), North America (after Webby, 1995; Ethington & Clark, 1982; Finney & Ethington, 1992, 2001; Ross et al., 1997), Baltic (Lindström, 1971; Löfgren, 1994; Bagnoli & Stouge, 1997), W. Newfoundland (Johnston & Barnes, 1999), Argentina (Albanesi et al., 1999, 2003), NW Russia (Tolmacheva et al., 2001, 2003) and Australia (Webby & Nicoll, 1989).

Stouge, 1997) and northwestern Russia (Tolmacheva et al., 2001, 2003, Dronov et al., 2003) correlates with the base of *B.?* *triangularis*-*M. flabellum* Biozone at Huanghuachang. The occurrence of *Azygograptus suecicus* together with *A. ellesi*, *Xiphograptus svalbardensis*, moreover, allows for the correlation of the base of *B.?* *triangularis*-*M. flabellum* Biozone at the Huanghuachang section with or close to the boundary between *lunatus* and *victoriae* graptolite Zones of the Australia standard (Webby & Nicoll, 1989) and other graptolite-bearing localities. The suggested correlation is further confirmed by the graphic correlation (Stouge et al., 2005). The worldwide low-stand event preceding the FAD of the *B.?* *triangularis* in the Huanghuachang section and the related carbon isotopic positive excursion are auxiliary physical and geochemical global markers.

We conclude that the level with FAD of *B.?* *triangularis* followed by *Microzarkodina flabellum* in the Huanghuachang section is recognizable globally in both shelly and shale facies based on conodonts, graptolites and chitinozoans. It is an extraordinary GSSP for global correlation and it has great potential to successfully serve as the base of the global Middle Ordovician Series and the lower stage, yet-to-be-named, for that series.

## Summary and formal proposal

The proposed Global Stratotype Section and Point for the base of the Middle Ordovician Series and the lower stage of the Middle Ordovician Series at the Huanghuachang section, near Yichang, Hubei, China fulfills all the basic requirements for a GSSP as follows:

The proposed GSSP is accessible. It is 22 km away from Yichang City and well exposed along the main road. A stone marker indicating the base of the Dawan Formation was set up in 1978 and is still standing.

The boundary interval is well exposed with adequate thickness. The structure is simple and the section is without structural disruptions.

The boundary is within a transgressive sequence and within an interval of uniform lithology, indicating continuous deposition in the boundary interval.

Various fossil groups, including conodonts, graptolites, trilobites, brachiopods, chitinozoans, and acritarchs are well represented in the boundary interval and allow for correlation into both North Atlantic and Midcontinent conodont provinces and Atlantic and Pacific graptolite provinces.

The conodonts are very abundant and diversified with several evolving lineages in the boundary interval. Associated graptolites plus well preserved and abundant chitinozoans and acritarchs provide auxiliary markers for the recognition and correlation of the boundary biohorizon in both shelly and graptolite facies.

The continuation of several evolving conodont lineages and the range of many additional species of conodonts, graptolites, chitinozoans and acritarchs across the boundary indicate the absence of any significant hiatus at the boundary.

The CAI values and the reflectance of organic-walled fossils indicate that the section with its low-grade metamorphism is suitable for palaeomagnetic and chemostratigraphic studies.

The first appearance of *B.?* *triangularis*, at the base of SHod16, 10.57 m above the base of the Dawan Formation, is proposed as the boundary biohorizon or point for the definition of the base of the global Middle Ordovician Series. This level is 0.2 m below the FAD of *Microzarkodina flabellum*, approximates the boundary between the lower and upper *Azygograptus suecicus* Biozones and nearly coincident with the base of the *Belonechitina henryi* chitinozoan Biozone. Thus, this biohorizon at the proposed GSSP can be recognized and correlated globally with high precision on the basis of a number of bioevents.

If the proposed GSSP is adopted, the Ministry of Land and Resources (MLR), PRC, the Government of Yichang City and Yichang Insti-

tute of Geology and Mineral Resources, MLR will erect a small park with the appropriate marker to ensure its protection.

## Acknowledgements

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## Appendix

Description of the Lower Dawan Formation of Huanghuachang section

### Dawan Formation:

**Middle Unit** (The lower-middle parts)

24. yellow green shale with limestone lenses, yielding *Azygograptus suecicus*, *Phyllograptus* (SHod-29) 1.5m
23. purplish red medium-bedded limestone with grayish-green shale interbeds (SHod25-28). 2.6m

**Lower Unit:** 12.97m

**Upper part:** 3m

22. grayish-green shale with nodular limestone (SHod24-22), containing the graptolites *Expansograptus*, *Xiphograptus svalbardensis* and *Pseudotrionograptus* sp. 0.80m
21. gray medium-bedded limestone with grayish-green shale interbeds (SHod21-20). 0.60m
20. grayish-green shale with a few nodular limestone, containing graptolites, *Azygograptus suecicus* *Xiphograptus svalbardensis* in the lower 0.3m. (SHod19) 0.50m
19. gray thin-bedded limestone intercalated with gray-greenish shale with limestone lenses, bearing conodonts, graptolites, chitinozoans and acritarchs (SHod18-12) (The Lower/Middle Ordovician boundary is defined at the base of SHod-16, 0.6m above the base of the bed SHod12) 1.10m.

**Middle part:** 4.52 m

18. gray purplish medium-bedded dolomitic limestone (SHod11-9). 0.9m
17. gray thin bedded bioclastic limestone with yellowish-green shale interbeds rich in shelly fossils (SHod8). 0.4m.
16. gray thin bedded nodular bioclastic limestone with yellowish-green shale interbeds (SHod7). 0.3m
15. gray thin bedded nodular bioclastic limestone with yellowish-green silty shale interbeds, bearing graptolites (SHod6). 0.6m
14. gray thin bedded nodular bioclastic limestone with yellowish-green silty shale interbeds rich in shelly fossils (SHod5). 0.5m
13. grey thin bedded glauconitic bioclastic limestone with silty mudstone and shale interbeds, bearing abundant shelly fossils (SHod4-SHod1) and rare graptolite at the bottom (SHod1). 0.92m
12. gray thin bedded bioclastic limestone intercalated with yellowish-green mudstone (Hod1-Hod3), yielding the first appearance of *Azygograptus suecicus* at the bottom (Hod3). 0.90m.
- Lower part: 5.45m
11. gray thin bedded nodular bioclastic limestone with yellowish-green mudstone and shale interbeds, yielding graptolites, *D.bifidus*, *D. deflexus* (Hod4) 0.17m
10. gray thin-bedded nodular limestone (Hod5). 0.13m
9. gray thin-bedded glauconitic nodular bioclastic limestone intercalated with silty mudstone (Hod6). 0.18m
8. gray thin-bedded coarse crystallized bioclastic limestone with silty mudstone and shale interbeds, bearing *D. bifidus* (Hod8, Hod7-9). 0.62m
7. gray thin-medium bedded coarse crystallized bioclastic limestone intercalated with silty shale. The limestone yields the last appearance of *Oepikodus evae* (Hod10). 0.20m.
6. gray thin-bedded coarse crystallized glauconitic bioclastic limestone intercalated with silty mudstone, containing the first appearance of *Oepikodus intermedius* (Hod11-16). 1.12m.
5. gray thin-bedded nodular coarse crystallized bioclastic limestone intercalated with silty mudstone and shale interbeds bearing *D. bifidus* (Hod18), (Hod17-19). 0.65m

4. gray thin-bedded nodular coarse crystallized bioclastic limestone in the upper part, medium-bedded bioclastic limestone in the lower part with a thin-bedded bed of silty shale (Hod20-21). 0.30m
3. gray medium bedded coarse bioclastic limestone with a silty shale interbeds yielding fragments of the graptolite *D. bifidus* at the top (Hod22). 0.20m
2. gray medium bedded coarse glauconitic bioclastic limestone with rare shale (Hod23-26). 0.95m.
1. gray thick-medium bedded coarse glauconitic bioclastic limestone (Hod27-29) with the first appearance of *Oepikodus evae* (Hod28). 0.93m
- Underlying strata: **Honghuayuan Formation:** light gray thick bedded dolomitic limestone with *Calathium*.

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