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pp. 309–321
figs. 1–5

西秦岭地区志留/泥盆系过渡带中的鱼类微体化石及其组合序列[1)]

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摘要：西秦岭是开展华南板块志留/泥盆系界线层序研究的一个重要地区。该区普通沟剖面中的志留/泥盆系过渡带包括羊路沟组上部和下普通沟组下部，产丰富的鱼类微体化石，包括花鳞鱼类、棘鱼类、软骨鱼类及盾皮鱼类。这些化石构成两个完全不同的鱼类微体化石组合：羊路沟组合和下普通沟组合。通过与波罗的海等地区鱼类微体化石带的对比，羊路沟和下普通沟组合的地质时代分别为志留纪普里道利世晚期和早泥盆世洛霍考夫期早期。西秦岭地区志留/泥盆系过渡带中的鱼类微体化石及其组合序列的研究，为该区志留/泥盆系界线的精确确定提供了重要的古鱼类学证据。

关键词：华南，西秦岭；志留系；泥盆系；鱼类微体化石组合

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THE MICROVERTEBRATE REMAINS AND ASSEMBLAGE SEQUENCES ACROSS THE SILURIAN/DEVONIAN TRANSITION IN WEST QINLING, CHINA

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Abstract West Qinling is an important area for the study of the Silurian/Devonian Boundary (SDB) in the South China Block. The SDB sequence in the Putonggou Section includes the upper part of the Yanglugou Formation and the lower part of the Xiaputonggou Formation, in which microvertebrate remains (thelodonts, placoderms, acanthodians and chondrichthyans) in association with conodonts and brachiopods have been collected. Two microvertebrate assemblages are recognized in the Putonggou Section: the Yanglugou Assemblage from the upper part of the Yanglugou Formation, and the Xiaputonggou Assemblage from the lower part of the Xiaputonggou Formation in association with the conodont *Icriodus woschmidti woschmidti*. The Yanglugou Assemblage yields the acanthodians *Gomphonchus*

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sandelensis and Ischnacanthidae gen. indet., and the Xiaputonggou Assemblage includes the thelodonts (*Parathelodus scitulus*, *P. asiaticus* and *P. cornuformis*), the acanthodians (*Nostolepis gracilis*, *N. striata*, *N. tewonensis*, *Gansuichthys liui*, *Poracanthodes zoigenensis*, *Poracanthodes* cf. *P. porosus, Ischnacanthys* sp.), the chondrichthyan (*Arauzia* ? sp.), and the placoderm (a pectoral fin fragment of *Chuchinolepis* ? sp.). Based on the correlation with the microvertebrate biozones in East Baltic, the Yanglugou and Xiaputonggou assemblages are referred to the Late Pridoli and the early Lochkovian respectively, thus providing paleoichthyological evidence for the location of the SDB in West Qinling.

Key words West Qinling, South China; Silurian; Devonian; microvertebrate assemblage

1 Introduction

In West Qinling, the continuous marine strata from Pridoli to Lower Devonian (i.e., Yanglugou and Xiaputonggou formations) are well exposed in Zoige (Sichuan Province) and Tewo (Gansu Province) regions, and have potential for the study of the Silurian/Devonian Boundary (SDB) sequence (Fig.1). The SDB sequence in the Putonggou Section (Zoige) consists primarily of the upper part of the Yanglugou Formation and the lower part of the Xiaputonggou Formation (XIGMR and NIGPAS, 1987a, b; Wang et al., 1998; Zhao et al., 2010). The upper part of the Yanglugou Formation comprises grey phyllite-like calcareous shale and thin-to thick-bedded limestone intercalated with argillaceous and bioclastic limestones, and the lower part of the Xiaputonggou Formation comprises mainly grey phyllite-like calcareous shales intercalated with limestones. Abundant fossils, such as conodonts, brachiopods and microvertebrate remains, were collected from the SDB sequence in the Putonggou Section, indicating a shallow sea shelf facies (XIGMR and NIGPAS, 1987a, b; Wang et al., 1998).

Wang et al. (1998) first reported the microvertebrate remains from West Qinling and described some acanthodian scales. Recently, we collected additional microvertebrate specimens across the SDB transition in the Putonggou Section, including thelodonts, acanthodians, chondrichthyans and placoderms. The purpose of this paper is to describe these remains, to recognize the different microvertebrate assemblages, and to discuss the SDB in the section in light of comparisons with contemporaneous microvertebrate assemblages in East Baltic which can be correlated to the standard graptolite and/or conodont biozonations (Blieck et al., 1988; Valiukevicius, 1988; Märss, 1989, 2000; Blieck and Janvier, 1993; Janvier and Blieck, 1993).

2 Samples and methods

Based on the previous biostratigraphic research (XIGMR and NIGPAS, 1987a, b; Wang

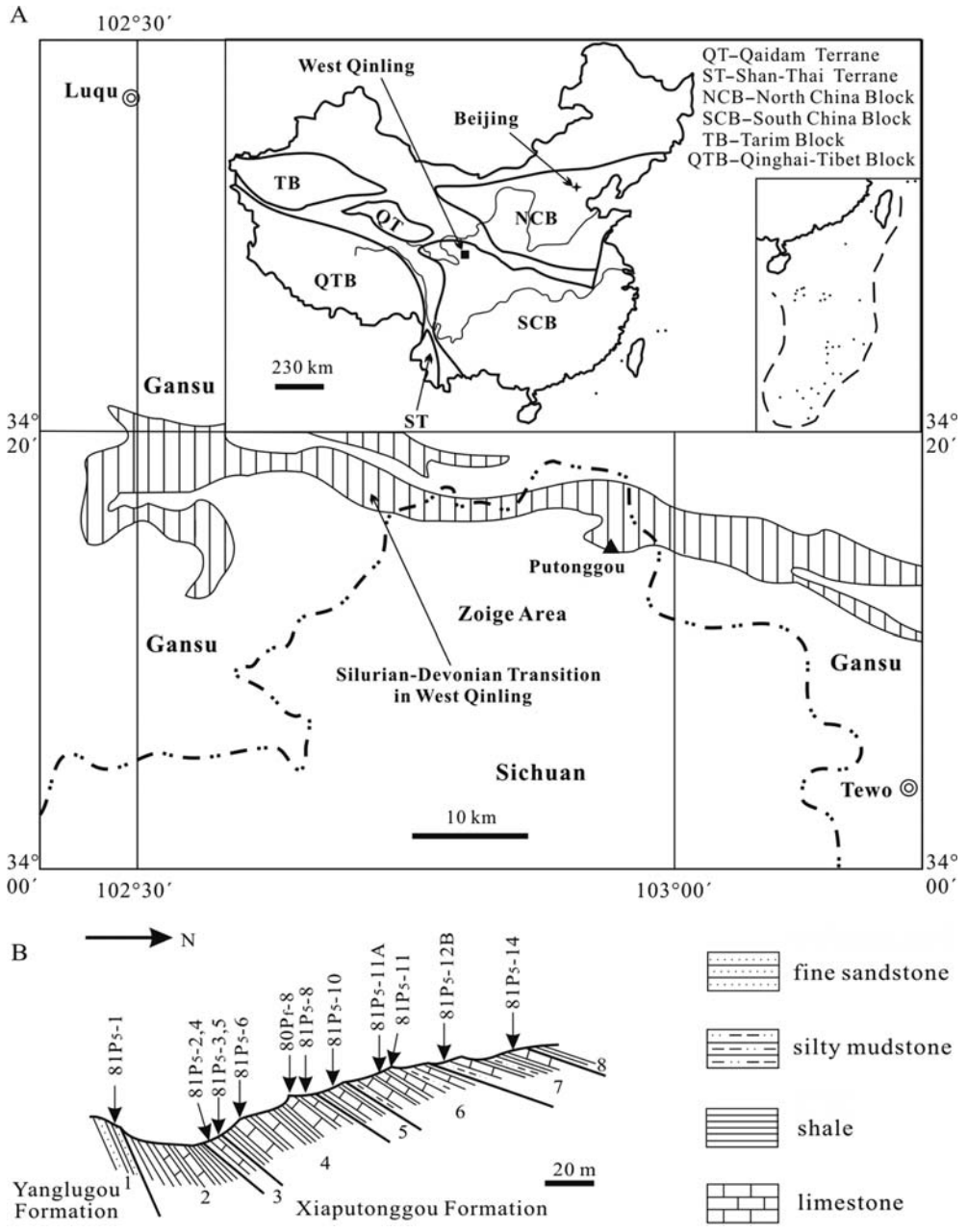

Fig. 1　Putonggou Section in West Qinling, China

A. Location of West Qinling on the map showing the tectonic units in China, and distribution of the Silurian/Devonian transition in West Qinling; B. Cross section showing the positions of the samples collected in 1981 (revised from XIGMR and NIGPAS, 1987a)

et al., 1998), we measured a 48 m section (Putonggou Section-ZP Section) spanning the SDB in West Qinling. The microfossil samples (each with about 1000 g weight) were collected from the section at approximately 1.5 m intervals.

The treatment of microfossil samples was processed in the Key Laboratory of Evolutionary Systematics of Vertebrates, Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences, China. Rich microvertebrate

remains were obtained after dilute (5%) acetic acid treatment. Some undescribed microvertebrate remains from three samples collected in 1981 (XIGMR and NIGPAS, 1987a) are also included in this study. All materials described here are housed in IVPP.

3 Systematic paleontology

Acanthodian remains, including Climatiidae (*Nostolepis striata* Pander, 1856, *N. gracilis* Gross, 1947, and *N. tewonensi*s Wang et al., 1998) and Ischnacanthidae (*Gomphonchus sandelensis* Pander, 1856, *Gansuichthys liui* Wang et al., 1998, and *Ischnacanthys* sp.), have been found from the microfossil samples of ZP-20, ZP-22 and ZP-28 in the Putonggou Section (Figs.2 and 5). The same acanthodian scales were described in detail mainly from the younger higher horizons (Figs.1B and 5, 81P_5-8, 11, 14, 18) in the lower part of Xiaputonggou Formation (Wang et al., 1998). In addition, the acanthodian ischnacanthids *Poracanthodes* cf. *P. porosus* and *P. zoigenensis* have also been reported from Xiaputonggou Formation in the Putonggou Section (Wang et al., 1998). Here, we will focus on description of newly-discovered

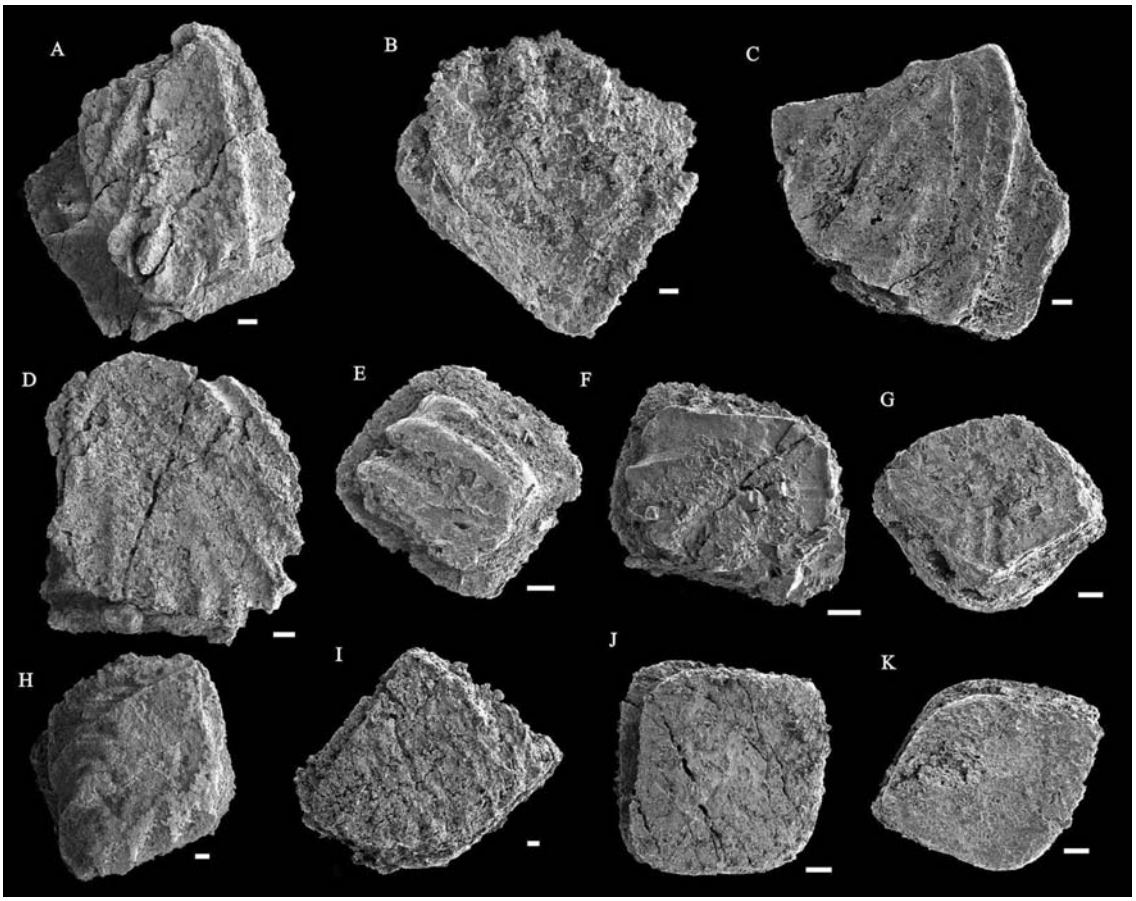

Fig. 2 Acanthodian scales (Climatiida and Ischnacanthida) in the Putonggou Section
A, B. *Nostolepis striata* Pander, 1856; C, D. *N. gracilis* Gross, 1947; E, F. *N. tewonensis* Wang et al., 1998; G. *Gomphonchus sandelensis* Pander, 1856; H, I. *Gansuichthys liui* Wang et al., 1998; J, K. *Ischnacanthys* sp.; all in crown view; scale bars = 0.1 mm

thelodonts, chondrichthyans and placoderms.

Class Agnatha Cope, 1889

Subclass Thelodonti Jaekel, 1911

Order Thelodontiformes Kiaer, 1932

Family Coelolepididae Pander, 1856

Genus *Parathelodus* Wang, 1997

***Parathelodus scitulus* Wang, 1997**

(Fig.3A—D)

Material Two body scales, IVPP V 15990.1 and V 15990.2.

Locality and horizon Lower member of the Xiaputonggou Formation (early Lochkovian), Sample 81P_5-14; Putonggou Section of Zoige County, Sichuan Province, China.

Description The scale crown has an arched anterior margin and two straight postero-lateral margins. The anterior margin of the crown is serrated with 6 to 7 small notches. The crown surface is either smooth (V 15990.1, Fig.3A, B) or with two short longitudinal fine ridges in the anterior part (V 15990.2, Fig.3C, D). The scale neck is distinct and smooth. The scale base is oval with a large central pulp opening, and smaller than the scale crown.

Remarks The scales in general shape resemble those of *Parathelodus scitulus* from the lower part of the Xitun Formation of Qujing, East Yunnan, China (Wang, 1995a, 1997). Wang (1995a, 1997) suggested *Parathelodus* as a transitional form between *Thelodus* and *Turinia*, based on its unique character combination. The scale neck with small stepped ridges in its posterior part is a character of *Thelodus*. Like *Turinia*, but in contrast to *Thelodus*, the dentine tubules radiating from the single pulp cavity are sparse and not distinctly sinuous (see plate I, F-H in Wang, 1997).

***Parathelodus asiaticus* Wang, 1997**

(Fig.3E—G)

Material Two body scales, IVPP V 15991.1 and V 15991.2.

Locality and horizon As for IVPP V 15990.

Description The scale crown is rhombic in shape. The crown surface is smooth and convex (V 15991.2, Fig.3G), or slightly convex with some parallel ridges (V 15991.1, Fig.3E, F). The crown has some small tubercles and fine ridges in its anterior margin and a thorn-shaped layer under the postero-lateral crown top. The neck wall is smooth. The rhombic scale base has a prominent anterior process and a small central pulp opening.

Remarks The scales dealt with herein resemble in some respects *Parathelodus asiaticus* from the lower part of the Xitun Formation of Qujing district, East Yunnan, China (Wang, 1984, 1995a,b, 1997). In general, the scales of *P. asiaticus* can be separated into head, transitional, and body scale types. The body scales of *P. asiaticus* possess an elliptical or rhombic crown, with a smooth but slightly convex surface, a smooth anterolateral margin,

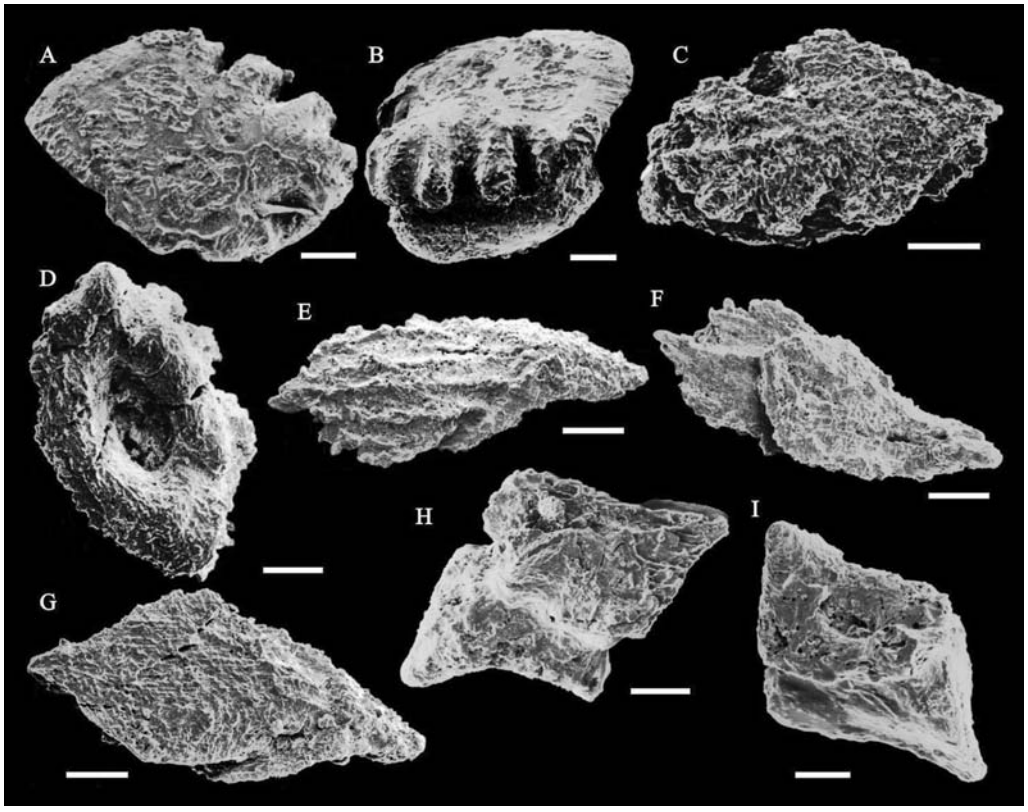

Fig. 3 Three representatives of the thelodonts in the Putonggou Section
A—D. *Parathelodus scitulus* Wang, 1997; E—G. *P. asiaticus* Wang, 1997; H—I. *P. cornuformis* Wang, 1997; A, C, E, G and H. in crown view; B. in lateral view; D, F, and I. in basal view; scale bars = 0.1 mm

and a smooth or dentate postero-lateral edge. In addition, the scale base is elongated to form a prominent anterior process, and has a small or medium size pulp opening in a posterior or central position (Wang, 1984). Thus two scales described herein should be referred to the body scale type.

***Parathelodus cornuformis* Wang, 1997**

(Fig.3H, I)

Material A body scale, IVPP V 15992.

Locality and horizon As for IVPP V 15990.

Description Scale bears a horn-like crown, with three ridges and two notches in the anterior margin; the neck is clear; the scale has a flat rhombic base, with a lower anterior process and a small central pulp opening.

Remarks The new specimen is similar to *Parathelodus cornuformis* from the lower part of the Xitun Formation of Qujing district, East Yunnan, China (Wang, 1995a, 1997). Märss et al. (2007) noted the presence of a horn-like crown, reminiscent of *Lanarkia* or *Thelodus traquairi*. However, the scales of *Lanarkia* and *Thelodus traquairi* usually possess a high and elongate crown, sometimes with an angular bend with coarse ribbing, which is different from the condition in *P. cornuformis*. Therefore, we keep *P. cornuformis* as a separate species.

Class Chondrichthyes Huxley, 1880
Order Hybodontiformes Maisey, 1987
Family incertae sedis
Genus *Arauzia* Mader, 1986
***Arauzia* ? sp.**

(Fig.4A, B)

Material A head scale, IVPP V 16000.

Locality and horizon Lower member of the Xiaputonggou Formation (early Lochkovian), Sample 81P_5-6; Putonggou Section of Zoige County, Sichuan Province, China.

Description A square-shaped scale carries six small polygonal tubercles at the crown surface; the scale neck is clear and constricted; the scale base, slightly larger than its crown, is thin and concave at its central part.

Remarks Type material of *Arauzia* derives from the middle Lochkovian Lebanza Formation, northern Spain (Mader, 1986). The head scale dealt with herein is referable in general shape to *Arauzia* (Zangerl, 1981; see table 6 and figs.2—3 in Mader, 1986) from the Lower Devonian of Spain, such as the shape of the scale crown and the thin scale base.

Class Placodermi M'Coy, 1848
Order Antiarcha Cope, 1885
Suborder Yunnanolepidoidei Miles, 1968
Family Chuchinolepidae Zhang, 1978
Genus *Chuchinolepis* Zhang, 1978
***Chuchinolepis* ? sp.**

(Fig.4C)

Material A fragment of pectoral fin, IVPP V 15999.

Locality and horizon Lower member of the Xiaputonggou Formation (early Lochkovian), Sample 81P_5-8; Putonggou Section of Zoige County, Sichuan Province, China.

Description A segment of the pectoral fin carries V-shaped ridges, and lacks any tubercles in between.

Remarks The fragment resembles in general shape the pectoral fin of *Chuchinolepis* (see plate I-3a in Zhang, 1984; plate X-7 and fig.25A in Zhu, 1996) from the Xitun Formation in Qujing district, Yunnan Province, China. However, this fragment of pectoral fin is different from that of Qujing in lacking any tiny tubercles between the ridges.

4 Microvertebrate assemblages across the SDB in West Qinling

The microvertebrate remains from the SDB sequence in the Putonggou Section include thelodonts, acanthodians, placoderms and chondrichthyans, in association with

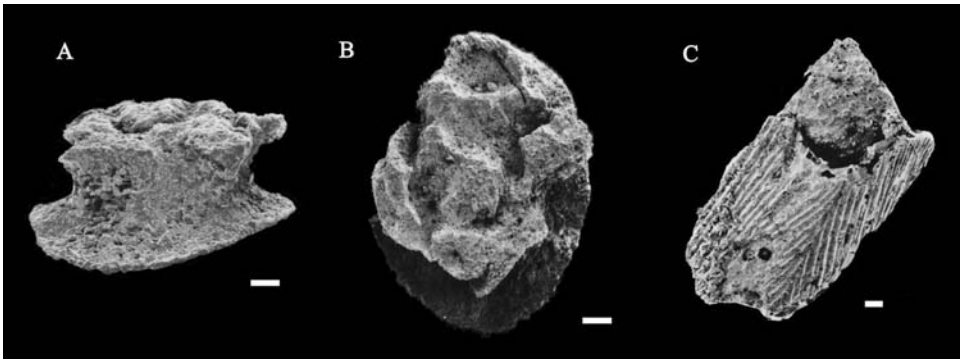

Fig. 4 Representatives of chondrichthyans (Hybodontiformes) and placoderms (Antiarcha) in the Putonggou Section
A—B. *Arauzia* ? sp.; C. *Chuchinolepis* ? sp. (a fragment of pectoral fin); A. in lateral view, B. in crown view; scale bars = 0.1 mm

corals, brachiopods, conodonts and spores (Wang, 1981; Li, 1987; XIGMR and NIGPAS, 1987a, b; Wang et al., 1998). While only the acanthodians (*Gomphonchus sandelensis* and Ischnacanthidae gen. indet.) are found from the Yanglugou Formation in West Qinling, the microvertebrate remains from the lower part of the Xiaputonggou Formation are abundant and diverse, including the thelodonts (*Parathelodus scitulus*, *P. asiaticus*, *P. cornuformis*), the acanthodians (*Gansuichthys liui*, *Nostolepis striata*, *N. gracilis*, *N. tewonensis*, *Gomphonchus sandelensis*, *Ischnacanthys* sp., *Poracanthodes zoigenensis*), and a chondrichthyan (*Arauzia* ? sp.). In addition, an antiarch pectoral fin fragment (*Chuchinolepis* ? sp.) has been collected from the lower part of the Xiaputonggou Formation in the Putonggou Section.

Zhao and Zhu (2010) introduced the composition of microvertebrate remains from West Qinling and recognized two microvertebrate assemblages from the SDB sequence of West Qinling, however a majority of these microremains have not been illustrated and described until this study. The first microvertebrate assemblage, the Yanglugou Assemblage (Zhao and Zhu, 2010), is represented by the acanthodians (*Gomphonchus sandelensis* and Ischnacanthidae gen. indet.) from the upper part of the Yanglugou Formation (Fig.5). In West Qinling, *Gomphonchus sandelensis* has a long duration from the upper part of the Yanglugou Formation to the lower part of the Xiaputonggou Formation, and an indeterminate form of Ischnacanthidae is confined within the Yanglugou Formation (Fig.5). The assemblage can be compared with the *Paracanthodes punctatus* acanthodian zone (containing *Gomphonchus sandelensis*)(Valiukevicius, 2000), in association with thelodont *Katoporadus* cf. *K. timanicus* from the latest Pridoli of the Welsh Borderland or *K. timanicus* from the latest Pridoli of East Baltic (Märss and Miller, 2004). In addition, the ischnacanthids are generally thought to be of the latest Pridoli age in China (Wang, 2003). Therefore, we suggest that the assemblage should be assigned to the latest Pridoli.

The second assemblage, the Xiaputonggou Assemblage (Zhao and Zhu, 2010), is characterized by the vertebrate micro-remains of thelodonts, acanthodians and chondrichthyans, in association with the vertebrate macro-remains of placoderms (*Chuchinolepis* ? sp.). All

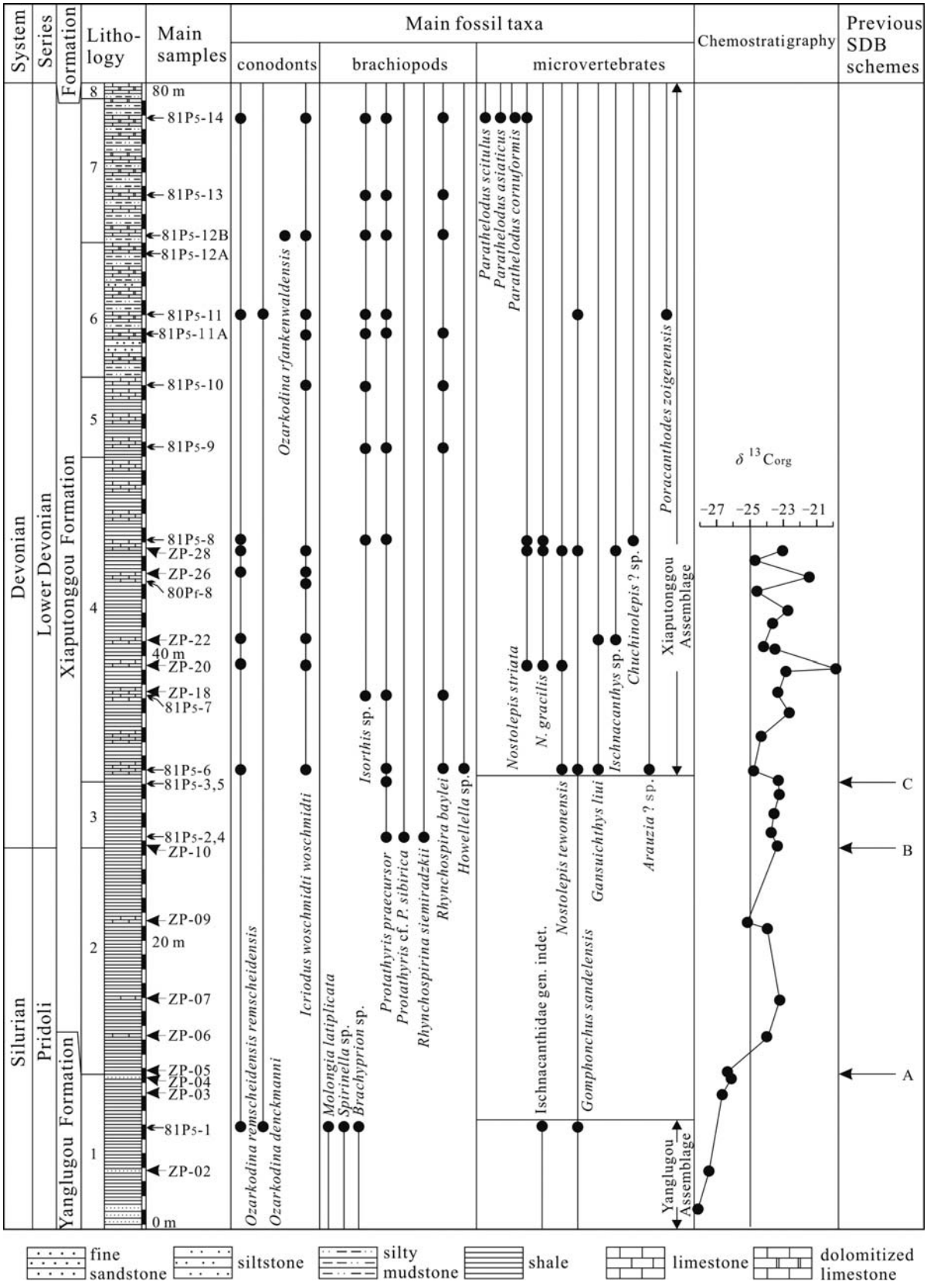

Fig. 5　Biostratigraphy and chemostratigraphy in the Putonggou Section, West Qinling

materials are collected from the lower part of the Xiaputonggou Formation in the Putonggou Section (Fig.5). The thelodonts from the section include *Parathelodus scitulus*, *P. asiaticus*, and *P. cornuformis*, which share with *Turinia* in sparse and no distinctly sinuous dentine tubules radiating from the single pulp cavity. In addition, the body scales of *P. asiaticus* from the Putonggou Section resemble in some respects those of *Turinia polita* and *Thelodus triloatus* from Europe (Turner, 1976; Karatajūte-Talimaa, 1978), suggesting that *P. asiaticus* may be close to the ancestry of the turiniids (Karatajūte-Talimaa, 1978). Thus, the thelodont genus *Parathelodus* from China (West Qinling and Yunnan) represents a transitional type between *Thelodus* and *Turinia* (Wang, 1995a, 1997). The chondrichthyans from the section are only represented by *Arauzia* ? sp., while the acanthodians from the section are diverse, including *Nostolepis striata*, *N. gracilis*, *N. tewonensis*, *Gomphonchus sandelensis*, *Gansuichthys liui*, *Ischnacanthys* sp., and *Poracanthodes zoigenensis* (Fig.5). The assemblage can be compared with the *Nostolepis minima* acanthodian zone that contains several species of *Nostolepis* (Valiukevicius, 2000), and the *Turinia pagei* thelodont biozone from the East Baltica and the Welsh Borderland (Märss and Miller, 2004). Valiukevicius (2000) suggested that the age of the *Nostolepis minima* zone is the same as that of the *woschmidti-postwoschmidti* conodont zone, and should be the earliest Lochkovian. In fact, the assemblage is associated with conodont *Icriodus woschmidti woschmidti* in the Putonggou Section (Wang, 1981; Li, 1987), which also gives the assemblage an earliest Lochkovian age. It is noteworthy that the vertebrate micro-remains and macro-remains in the Xiaputonggou Assemblage, such as three common species of thelodonts (*Parathelodus scitulus*, *P. asiaticus* and *P. cornuformis*), acanthodians *Nostolepis* and Ischnacanthidae, and placoderms *Chuchinolepis*, have also been discovered in the Xishancun and Xitun formations of Qujing, Yunnan Province (Zhang, 1978, 1984; Wang, 1984; Wang and Dong, 1989; Zhu, 1996; Wang, 1997), indicating the related strata (such as the Xiaputonggou, Xishancun and Xitun formations) can be well correlated.

5 Discussions

The GSSP (Global Standard Section and Point) of the SDB is defined at the base of the zone containing the graptolite *Monograptus uniformis uniformis*, together with the first occurrence of the trilobite *Warburgella rugulosa rugosa* and the conodont *Icriodus woschmidti woschmidti* (Chlupáč et al., 1972, 1998; McLaren, 1977). However, except *I. w. woschmidti*, the other two indicator fossils of the boundary cannot be found in the Putonggou Section of West Qinling. Furthermore, *I. w. woschmidti* is always found a little lower than the first occurrence of *M. u. uniformis* in Podolia, Bohemia and Nevada, conversely in Carnic Alps (the border between Austria and Italy) and in Rabat-Tiflet area of Morocco, which brings a considerable difficulty to the location of the exact SDB in West Qinling (Rong et al., 1987).

Up to now, the SDB in West Qinling has remained contentious, although many biostratigraphic and chemostratigraphic attempts have been made to define its exact level

(Rong et al., 1987; XIGMR and NIGPAS, 1987a; Zhao et al., 2010). Three main stratigraphic schemes attempted to clarify the SDB in the Putonggou Section (Fig.5). Based on the first occurrence of *I. woschmidti woschmidti*, the SDB was placed at the base of the bed No. 4 of the Xiaputonggou Formation (Scheme C, XIGMR and NIGPAS, 1987a). Rong et al. (1987) suggested that the SDB should be placed at the base of the bed No.3 of the Xiaputonggou Formation (Scheme B) based on the changes of brachiopod faunas, which was confirmed by the study of carbon isotope stratigraphy (Zhao et al., 2010). The lithostratigraphical changes together with the study of complex stratigraphy supported that the SDB was placed at the base of the Xiaputonggou Formation (Scheme A, XIGMR and NIGPAS, 1987a).

The above-mentioned study on the microvertebrate remains and assemblage sequences shows that a continuous microvertebrate record exists from the Late Silurian to Early Devonian in West Qinling. It adds to our knowledge on the SDB biota and helps to locate the position of the SDB in West Qinling. The SDB in West Qinling can be placed between two different microvertebrate assemblages (i.e., the Yanglugou Assemblage of latest Pridoli and the Xiaputonggou Assemblage of earlist Lochkovian) recognized from the Putonggou Section, or between Sample ZP-02 (or $81P_5$-1) and Sample ZP-15 (or $81P_5$-6), although a gap of about 25 m span still exists between these two assemblages (Fig.5). The result is consistent with the present biostratigraphic and chemostratigraphic definition of the SDB in the Putonggou Section, West Qinling. Taking all available data into consideration, we suggest that the preferable SDB in the Putonggou Section can be placed at the base of the bed No.3 of the Xiaputonggou Formation, in between Sample ZP-09 and Sample ZP-10, and in accordance with Scheme B.

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