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Carboniferous conodont biostratigraphy of the Dianzishang section, Zhenning, Guizhou, South China

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Abstract – A preliminary summary of the lower Visean to uppermost Moscovian (Carboniferous) conodont succession and biostratigraphy of the Dianzishang section in Zhenning, Guizhou, South China is presented. Eleven conodont zones, in ascending order, can be recognized: *Gnathodus praebilineatus*, *Gnathodus bilineatus*, *Lochriea ziegleri*, *Declinognathodus noduliferus*, *Neognathodus symmetricus*, '*Streptognathodus*' *expansus* (primitive form), '*Streptognathodus*' *expansus*, *Mesogondolella donbassica – Mesogondolella clarki*, *Idiognathodus podolskensis*, *Swadelina* fauna and *Idiognathodus swadei* zones. The first occurrences of *Lochriea ziegleri* at the base of the Serpukhovian Stage, *Declinognathodus noduliferus noduliferus* at the base of the Bashkirian Stage and '*Streptognathodus*' *expansus* at the base of the Moscovian Stage are recognized. The definitions of these stage boundaries, as well as that of the base of the Kasimovian Stage are discussed. Correlations with the Naqing section in South China, Russian and North American sections, as well as other important sections in the world, are considered.

Keywords: Carboniferous, conodont biostratigraphy, Dianzishang section, Guizhou, South China.

1. Introduction

Global tectonics combined with Gondwanan glaciation confounds the subdivision of the Carboniferous and also complicates global correlations. Four Carboniferous stages, including the Serpukhovian of the Mississippian and the Moscovian, Kasimovian and Gzhelian of the Pennsylvanian still do not have Global Stratotype Sections and Points (GSSPs). Four Task Groups were therefore established ten years ago to search for their candidate GSSPs worldwide.

Marine Carboniferous sediments are well developed and widely distributed in South China. Sections with continous carbonate-dominated successions are especially well exposed in Guizhou Province of South China, among which the most representative section is the Naqing section in Luosu, Luodian of Guizhou. It is a candidate section for the GSSPs of the global Serpukhovian, Moscovian, Kasimovian and the Gzhelian stages at present, of which abundant conodonts and foraminifers have been densely studied in the last decade (Wang & Qi, 2003, 2007; Qi & Wang, 2005; Qi *et al.* 2007, 2009, 2010*a*, 2010*b*, 2010*c*, 2011, 2012; Wang *et al.* 2008, 2011; Barrick *et al.* 2010; Groves *et al.* 2012). The Naqing section is a relatively deep-water section of slope to basin facies containing abundant conodonts, but its foraminifers are not abundant enough for the study of the correlation of the conodont succession with the foraminiferal succession. The other sections of shallower water facies including the Yashui section, the Luokun section, the Dianzishang section, the Narao section and the Fengting section have therefore been studied in recent years.

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The Dianzishang section was measured and described by the Guizhou Geological Survey during the mapping project for the 1:200 000 geological map of the Wangxingren region (Bureau of Geology and Mineral Resources of Guizhou Province, 1987), while its microfossil succession has been little studied. A preliminary conodont succession and biostratigraphy from lower Visean to uppermost Moscovian in this section is reported in this paper.

The Visean–Moscovian duration not only contains several important stage boundaries, but also records several important geological and biotic events such as initiation of the Late Palaeozoic ice age and Middle Carboniferous mass extinction. The conodont zonation documented here provides the high-resolution time frameworks required for future studies concerning the above events.

2. The studied section, geological and stratigraphic settings

The Dianzishang section (25° 49′ 18″ N, 105° 52′ 35″ E) is located in Shazi, Zhenning, Anshun, Guizhou Province, a distance of 40 km from Zhenning County and 50 km from the city of Anshun. The section can be conveniently accessed by highway from Guiyang and Anshun (Fig. 1). It is part of the eastern limb of the Douluo anticline, which lies within the NW Shuicheng–Ziyun deformation zone (Wang, 2000). Palaeogeographically, the section was situated on a middle-slope of the platform south of Upper Yangtze Old Land. A succession of sediments from the Visean to the Moscovian is well exposed, except for a 10 m covered interval of middle Bashkirian

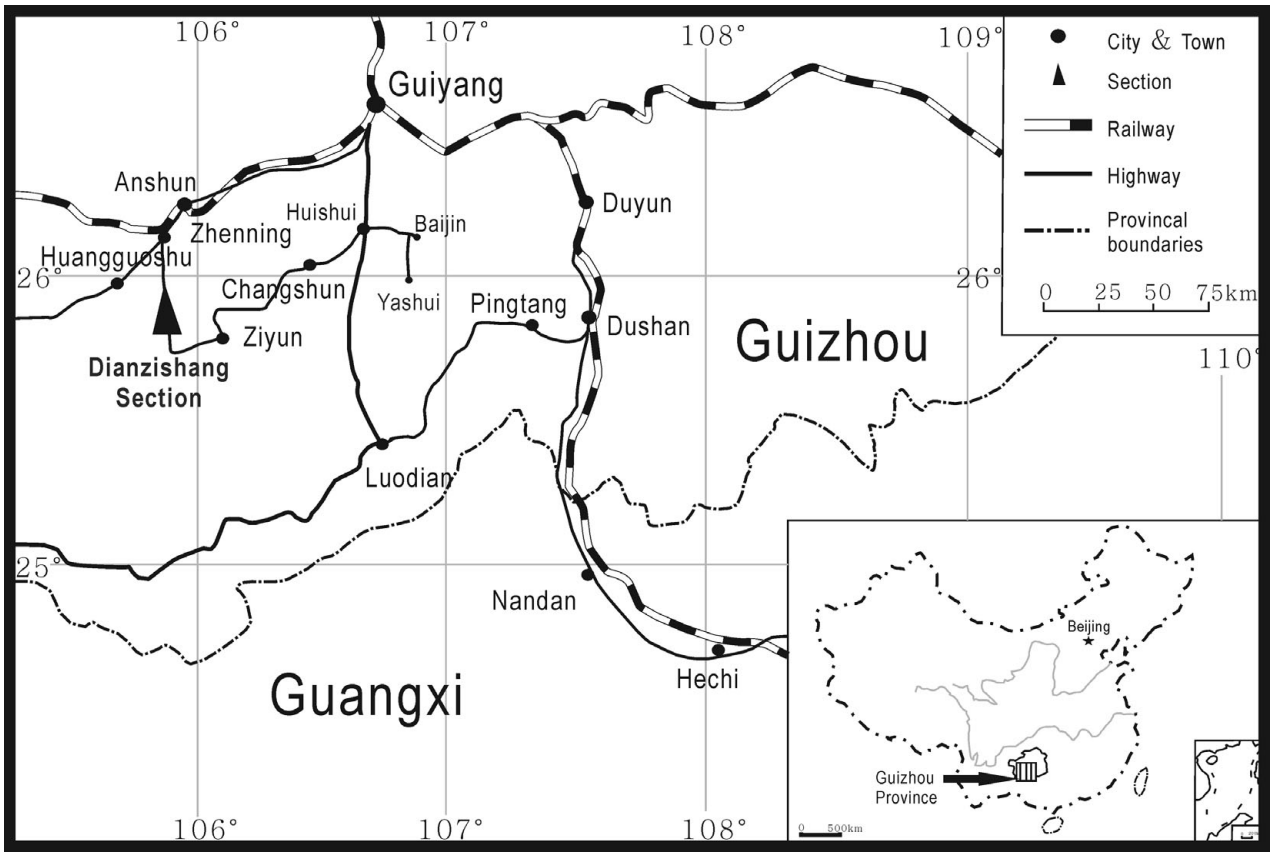

Figure 1. Location map of the Dianzishang section.

age. The Dianzishang section is mainly composed of greyish-black to black, thin- to medium-bedded packstone, wackestone and chert, intercalated with thick bedded grainstone but includes minor shale and slope breccias or slump deposits. This distinctive lithological succession is usually termed the 'Black Zone' in the Langdai–Luodian sedimentary zone.

The Dianzishang section can be subdivided into two parts (Fig. 2). The lower part is called the Xiaoxibian section, with a thickness of 80.08 m, and includes the beds from Visean to Bashkirian age. The upper part is called the Dalubian section, with a thickness of 94.44 m, and includes the beds from Bashkirian to Moscovian age. About 10 m of section between the lower part and the upper part are covered.

3. Conodont biostratigraphy and correlation

The Dianzishang section is composed of typical middle- to upper-slope sediments that mainly contain microfossils such as conodonts and foraminifers. Only conodonts are considered in this paper.

A total of 56 conodont species/subspecies (including more than 10 undetermined forms) belonging to 14 genera are identified (Fig. 3). Eleven conodont zones (sections 3.a.1–3.a.2, 3.b.1, 3.c.1–3.c.3, 3.d.1–3.d.5) are recognized from base to top, which are easily correlated with those of the Naqing section in South China, Russian and North American sections, as well as other important sections in the world (Fig. 4).

3.a. Visean

3.a.1. Gnathodus praebilineatus Zone (DZSC2.0–27.6; Fig. 5)

The base of this zone is marked by the First Appearance Datum (FAD) of *Gnathodus praebilineatus* Belka, 1985 and its top by the FAD of *G. bilineatus remus* Meischner & Nemyrovska, 1999 or *G. bilineatus romulus* Meischner & Nemyrovska, 1999. Presently, the base of this zone is not recognized in the Dianzishang section. This zone is characterized by the occurrence of *G. praebilineatus*, associated with other common forms such as *Gnathodus delicatus* Branson & Mehl, 1938, *G. girtyi girtyi* Hass, 1953, *G. girtyi meischneri* (Austin & Husri, 1974), *Lochriea comutata* (Branson & Mehl, 1941) and *Pseudognathodus homopunctatus* (Ziegler, 1960). This zone is the highest conodont zone in the Lower Visean. Previously, this zone has only been recognized in North Africa (Nemyrovska *et al.* 2006). It can be roughly correlated with the *Hindeodus scitulus – Apatognathus scalenus* Zone in North America (Lane & Brenckle, 2001).

3.a.2. Gnathodus bilineatus Zone (DZSC27.6–49.0)

The base of this zone is marked by the FAD of *Gnathodus bilineatus remus* or *G. bilineatus romulus*

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Figure 2. Photographs showing the Dianzishang section. (a, b) Upper part of the section (Dalubian section); and (c, d) lower part of the section (Xiaoxibian section).

and its top by the FAD of *Lochriea nodosa* (Bischoff, 1957). *L. nodosa* has not yet been found in the Dianzishang section. Other commonly associated forms are *G. bilineatus bilineatus* (Roundy, 1926), *G. delicatus*, *G. praebilineatus*, and *L. comutata* (Branson & Mehl, 1941). This zone is the lowest conodont zone in the upper Visean. It is also recognized in the Naqing section from Guizhou, South China (Y. P. Qi, unpub. Ph.D. thesis, Graduate University of Chinese Academy of Sciences, 2008) and the Genicera (= Alba) Formation from the Cantabrian Mountains, Spain (Nemyrovska, 2005). It can be correlated with the *G. bilineatus bilineatus* Zone and *L. mononodosa* (Rhodes, Austin & Druce, 1969) zone from the Verkhnyaya Kardailovka section, South Urals (Nikolaeva *et al.* 2002) and the lower part of the *G. girtyi collinsoni* Zone from the Asbian of Britain and Ireland (Higgins, 1975, 1985).

3.b. Serpukhovian

3.b.1. Lochriea ziegleri Zone (DZSC49.0–59.4; Fig. 5)

The base of this zone is marked by the FAD of *Lochriea ziegleri* (Nemirovskaya *et al*. 1994) and its top by the FAD of *L. cruciformis* (Clarke, 1960) (Qi & Wang, 2005). *L. cruciformis* has not yet been found in the Dianzishang section. Other commonly associated forms are *Gnathodus bilineatus bilineatus*, *G. bilineatus remus*, *G. delicatus*, *G. praebilineatus*, *L. comutata*, *L. costata* Pazukhin & Nemirovska in Kulagina *et al*. 1992, *L. monocostata* Pazukhin & Nemirovskaya in Kulagina *et al*. 1992 and *L. mononodosa*. This zone is the lowest conodont zone in the Serpukhovian. It is also recognized in the Naqing section from South China, Cantabrian Mountains from Spain, Moscow Basin from Russia, South Urals, Donetz Basin and various locations in Eurasia (Nemirovskaya *et al.* 1994; Skomposki *et al.* 1995; Nikolaeva *et al.* 2002; Nemyrovska, 2005; Qi & Wang, 2005; Y. P. Qi, unpub. Ph.D. thesis, Graduate University of Chinese Academy of Sciences, 2008). This zone is coeval with the lower part of *G. girtyi simplex – Kladognathus* Zone in Britain and Ireland (Higgins, 1975, 1985) and the uppermost *G. bilineatus* Zone to lower part of *Cavusgnathus naviculus* Zone from North America (Lane & Straka, 1974; Lane & Brenckle, 2001).

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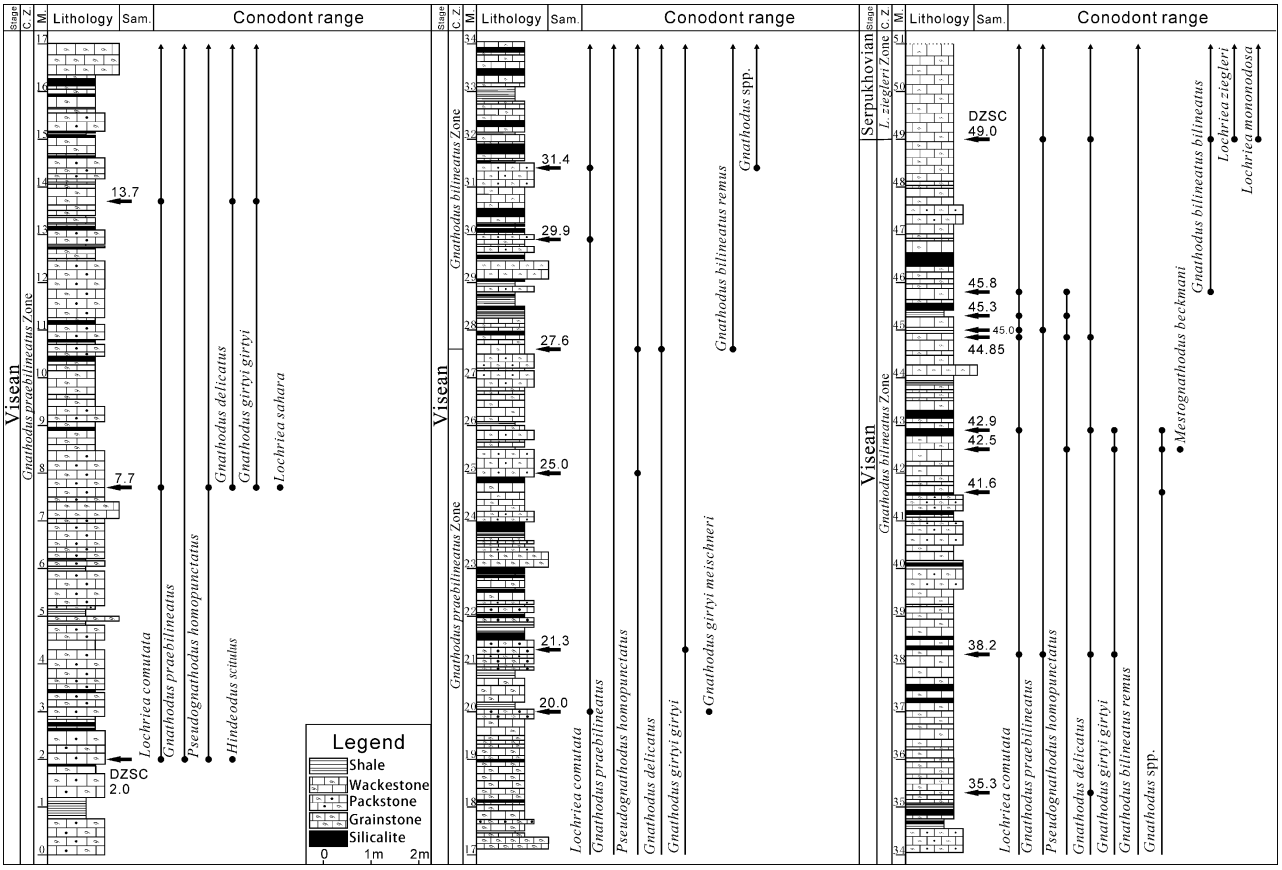

Figure 3. Conodont range chart for the Dianzishang section: (a) Visean–Serpukhovian; (b) Serpukhovian–Bashkirian–Moscovian; (c) Moscovian; and (d) Moscovian–Kasimovian.

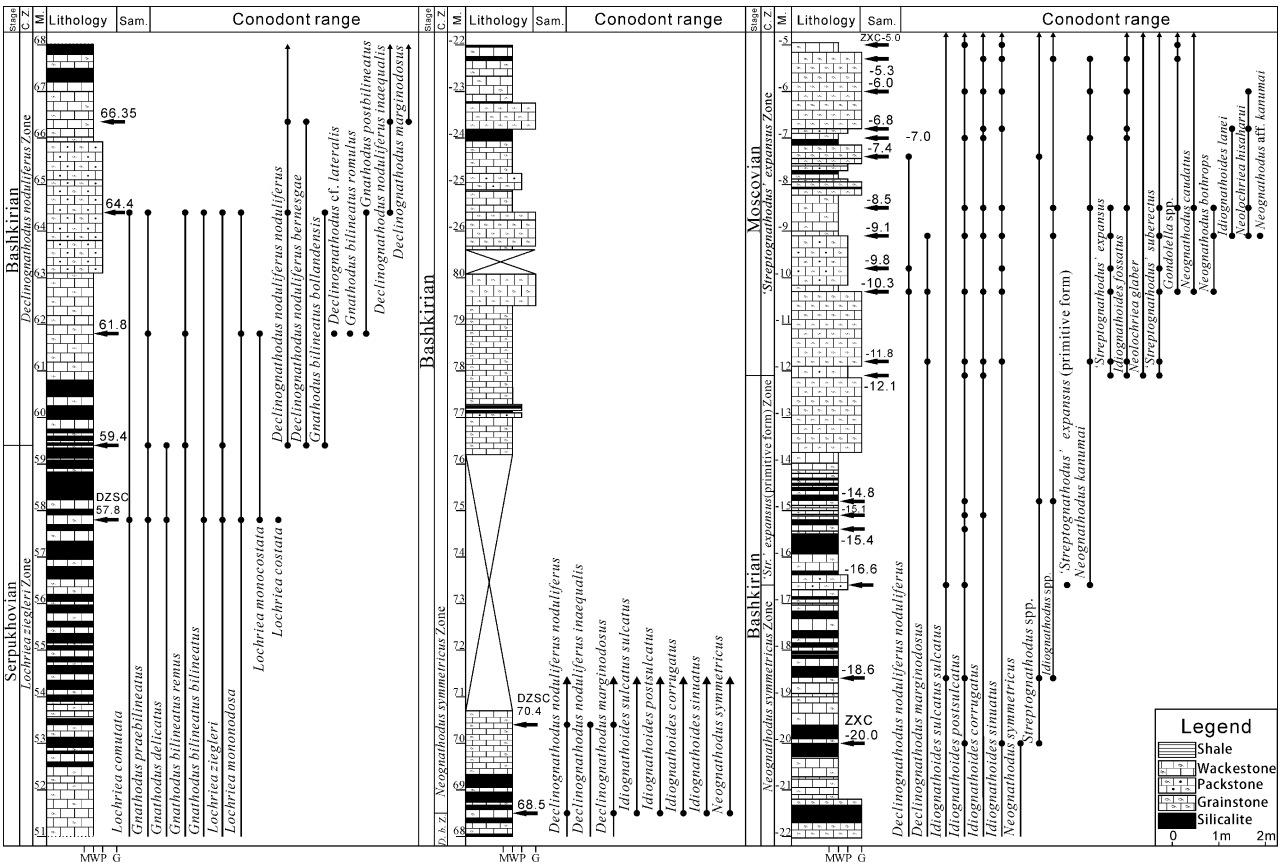

Figure 3. Continued.

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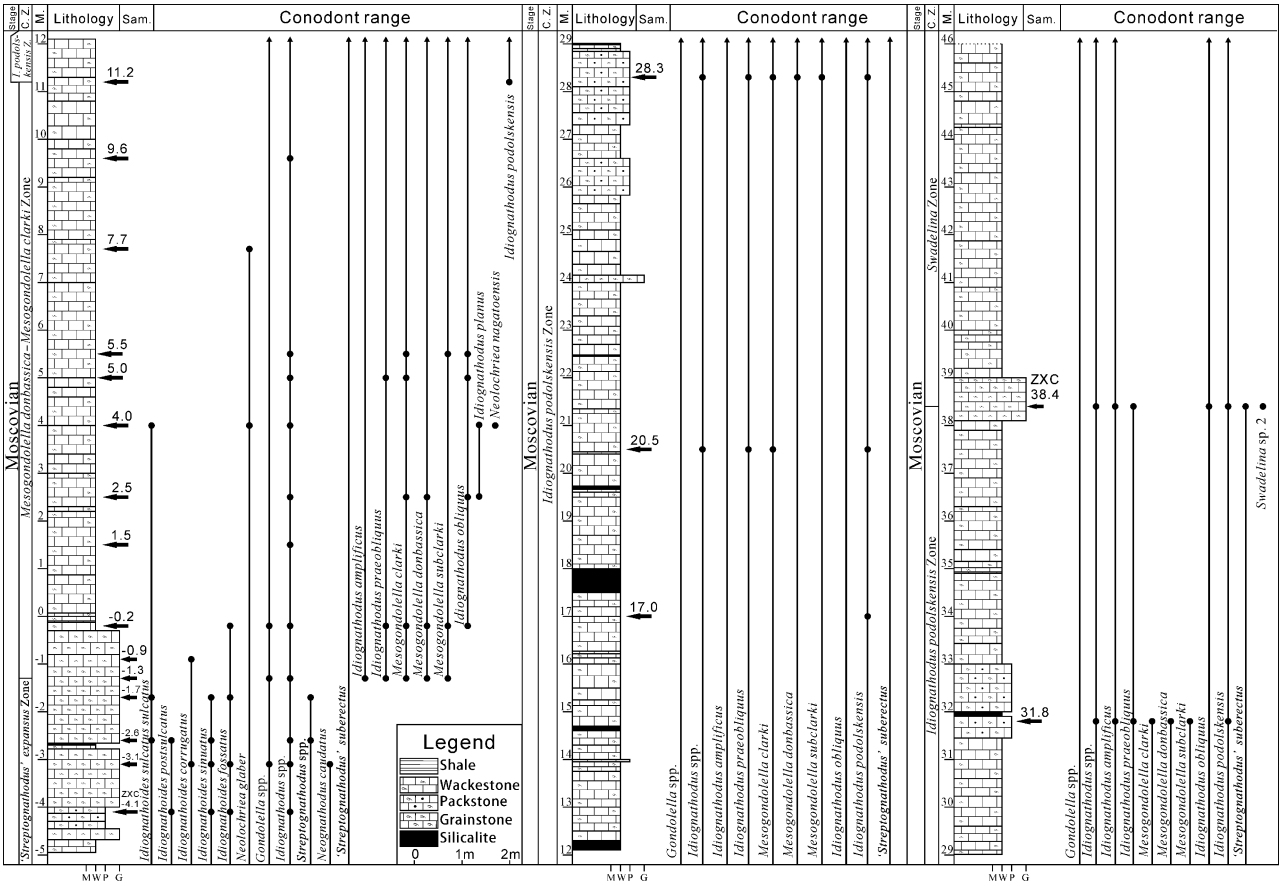

Figure 3. Continued.

3.c. Bashkirian

3.c.1. Declinognathodus noduliferus Zone (DZSC59.4–68.5; Figs 5, 6)

The base of this zone is marked by the FAD of *Declinognathodus noduliferus noduliferus* (Ellison & Graves, 1941) and its top by the FAD of *Idiognathoides sulcatus sulcatus* Higgins & Bouckaert, 1968 (Wang & Qi, 2003). Other commonly associated forms are *D.* cf. *lateralis* (Higgins & Bouckaert, 1968), *D. marginodosus* (Grayson, 1984), *D. noduliferus bernesgae* Sanz-Lopez, Blanco-Ferrera, Garcia-Lopez & De Posada, 2006, *D. noduliferus inaequalis* (Higgins, 1975) and *D. noduliferus noduliferus*, together with a few *Gnathodus bilineatus bilineatus*, *G. bilineatus bollandensis* Higgins & Bouckaert, 1968, *G. bilineatus remus*, *G. bilineatus romulus*, *G. postbilineatus* Nigmadganov & Nemirovskaya, 1992, *Lochriea comutata*, *L. monocostata*, *L. mononodosa* and *L. ziegleri*. The ranges of species of *Gnathodus* and *Lochriea* extend only to the bottom or middle part of this zone in the Dianzishang section. This zone is widespread over the world in the areas which were not strongly affected by the Middle Carboniferous eustatic event and where the Middle Carboniferous boundary deposits do occur (Nemyrovska, 1999; Nemirovska & Alekseev, 1994; Lane & Straka, 1974; Higgins, 1975, 1985; Wang *et al.* 1987; Perret, 1993).

3.c.2. Neognathodus symmetricus Zone (DZSC68.5–ZXC−16.6; Fig. 6)

The base of this zone is marked by the FAD of *Neognathodus symmetricus* (Lane, 1967) and its top by the FAD of *N. bassleri* (Harris & Hollingsworth, 1933). *N. bassleri* has not yet been found in the Dianzishang section. Other commonly associated forms in this zone are *Declinognathodus marginodosus*, *D. noduliferus inaequalis*, *D. noduliferus noduliferus*, *Idiognathoides corrugatus* Harris & Hollingsworth, 1933, *Id. postsulcatus* Nemyrovska, 1999, *Id. sinuatus* Harris & Hollingsworth, 1933, *Id. sulcatus sulcatus, Streptognathodus* sp. and *Idiognathodus* sp. This zone can be correlated with the *N. symmetricus* Zone to *I. primulus – N. symmetricus* Zone at the Naqing section (Wang & Qi, 2003; Wang *et al.* 2004). It is coeval with the same zone in North America (Lane & Straka, 1974; Barrick *et al.* 2004) and the *Neognathodus askynensis – N. symmetricus* Zone in South Urals, Russia (Nemirovska & Alekseev, 1994; Kulagina *et al.* 2009).

3.c.3. 'Streptognathodus' expansus (primitive form) Zone (ZXC−16.6 – −12.1; Fig. 6)

The base of this zone is marked by the FAD of '*Streptognathodus*' *expansus* (primitive form) and its

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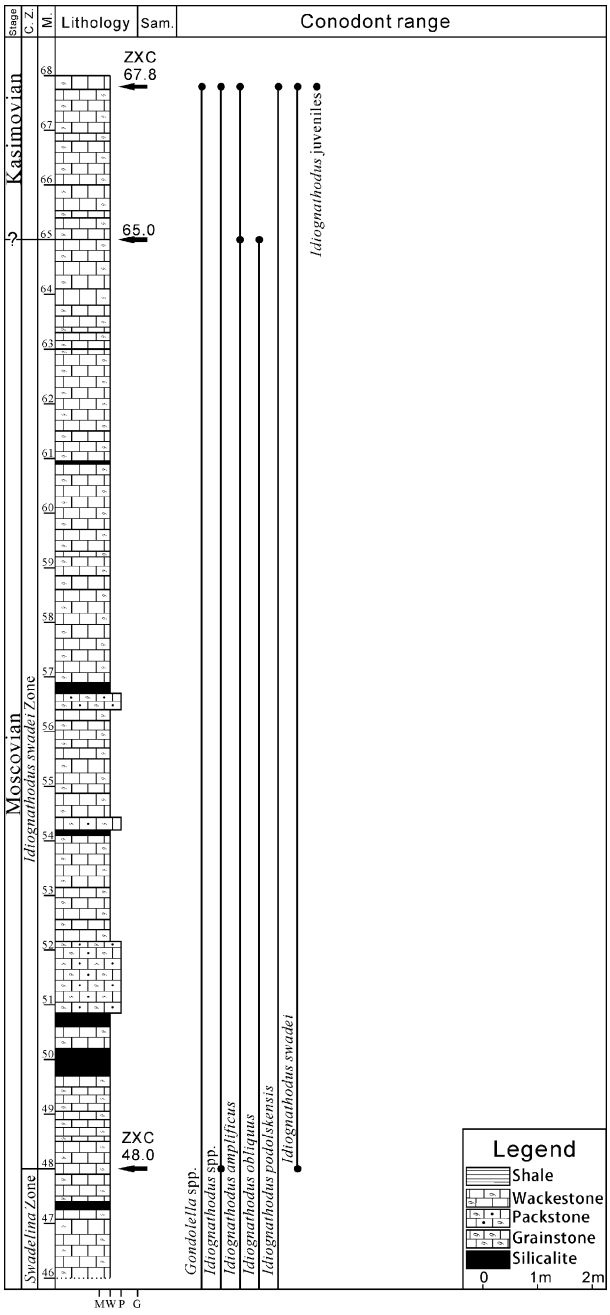

Figure 3. Continued.

top by the FAD of '*S.*' *expansus* Igo & Koike, 1964. Other commonly associated forms are *Declinognathodus marginodosus*, *Idiognathoides corrugatus*, *Id. postsulcatus*, *Id. sinuatus* and *Id. sulcatus sulcatus.* This zone can be correlated with the '*Streptognathodus preexpansus*' Zone from the Naqing section (Qi *et al.* 2011) and the *Idiognathoides sulcatus parva* Zone in Western Europe (Higgins, 1975, 1985), and it can be roughly correlated with the *Idiognathodus sinuosus* Ellison & Graves, 1941 Zone in Russia and North America (Lane & Straka, 1974; Nemirovska & Alekseev, 1994; Nemyrovska, 1999; Wang & Qi, 2003; Kulagina *et al.* 2009). It is also coeval with the previously established *Idiognathoides sulcatus parva* Zone in the Naqing section (Wang *et al.* 2004). (Note that '*Streptognathodus preexpansus*' is a new and unpublished species, here identified as '*Streptognathodus*' *expansus* (primitive form).) '*Streptognathodus*' *expansus* (primitive form) is used here to replace the unpublished species name and the name of the conodont zone.)

3.d. Moscovian

3.d.1. 'Streptognathodus' expansus Zone (ZXC−12.1 – −1.3; Figs 6–8)

The base of this zone is marked by the FAD of '*Streptognathodus*' *expansus*. The top of this zone is defined as the FAD of *Diplognathodus ellesmerensis* (Qi *et al.* 2011), but *D. ellesmerensis* has not yet been found in the Dianzishang section. Other commonly associated forms are *Idiognathoides corrugatus*, *Id. fossatus* (Branson & Mehl, 1941), *Id. lanei* Nemirovskaya, 1978, *Id. postsulcatus*, *Id. sinuatus*, *Id. sulcatus sulcatus*, *Neolochriea glaber* (Wirth, 1967), *Neol. hisaharui* Mizuno,1997, *Neognathodus bothrops* Merrill, 1972, *N. caudatus* Lambert, 1992, *N. kanumai* Igo, 1974, '*S.*' *suberectus* (Dunn, 1966), *Gondolella* spp., *Idiognathodus* spp. and *Streptognathodus* spp. This zone is also recognized in the Naqing section (Qi *et al.* 2011). It is coeval with the previously established conodont zones in the Naqing section such as '*S.*' *expansus* and *Id. ouachitensis* zones (Wang *et al.* 2004) and the '*S.*' *expansus*, *Id. ouachitensis* and *Diplognathodus coloradoensis* zones (Wang *et al.* 2008). It can also be correlated with '*S.*' *expansus*, *Idiognathoides tuberculatus-Id. fossatus* and *Declinognathodus marginodosus* zones in the Donets Basin, Ukraine (Nemyrovska, 1999), *Declinognathodus marginodosus* Zone in South Urals, Russia (Nemirovska & Alekseev, 1994; Nemyrovska, 1999; Kulagina *et al.* 2009), *Idiognathodus klapperi*, *Idiognathoides convexus* and *Id. ouachitensis* zones in North America (Lane, 1977; Lane *et al.* 1985) and the '*S.*' *expansus–'S.*' *suberectus* Zone in Nevada, USA (Dunn, 1970).

3.d.2. Mesogondolella donbassica – Mesogondolella clarki Zone (ZXC−1.3–11.2; Figs 7–9)

The base of this zone is marked by the FAD of *Mesogondolella donbassica* Kossenko, 1975 or *M. clarki* (Koike, 1967) and its top by the FAD of *Idiognathodus podolskensis* Goreva, 1984 (Wang *et al.* 2008; Y. P. Qi, unpub. Ph.D. thesis, Graduate University of Chinese Academy of Sciences, 2008). Other commonly associated forms are *I. amplificus* Lambert, 1992, *I. obliquus* Kossenko in Kozitskaya *et al.* 1978, *I. praeobliquus* Nemyrovska, Perret-Mirouse & Alekseev, 1999, *M. subclarki* Wang & Qi, 2003, *Neolochriea glaber*, *Gondolella* sp. and *I.* sp. This zone is also recognized in the Naqing section, and can be roughly correlated with the *Streptognathodus transtivus*, *Neognathodus bothrops*, *N. medadultimus* and *Streptognathodus concinus–Idiognathodus robustus* zones in Russia (Kulagina *et al.* 2009), and with the *N. bothrops* Zone, *N. caudatus* Zone

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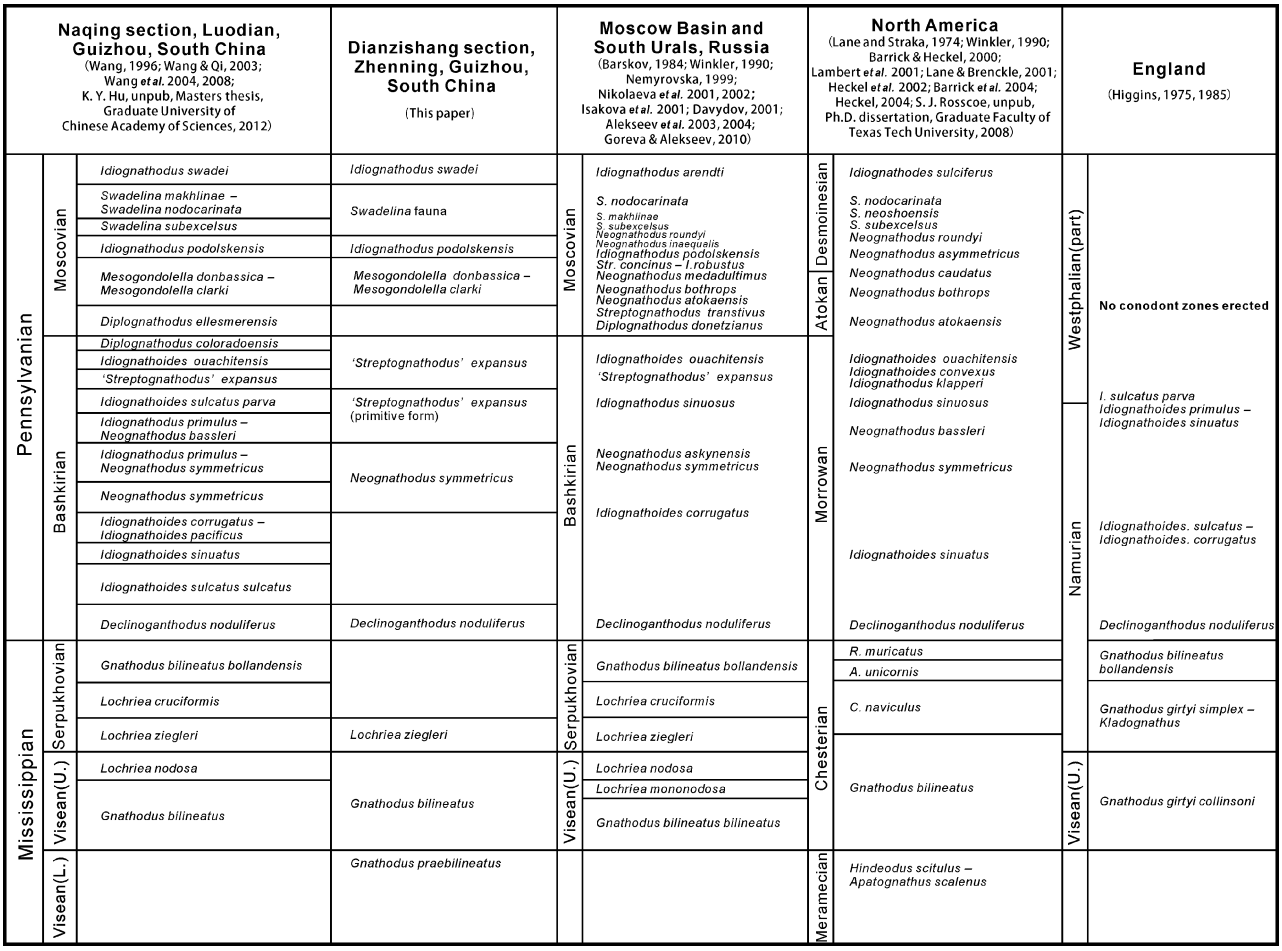

Figure 4. Conodont zones of the Dianzishang section and their correlations.

and the lower part of the *N. asymmetricus* Zone in North America (Barrick *et al.* 2004; Wang & Qi, 2003; Wang *et al.* 2008).

3.d.3. Idiognathodus podolskensis Zone (ZXC 11.2–38.4; Figs 7–9)

The base of this Zone is marked by the FAD of *Idiognathodus podolskensis* and its top by the FAD of any species of *Swadelina*. Other commonly associated forms are *I. amplificus*, *I. planus* Furduj, 1979, *I. praeobliquus*, *I. obliquus*, *Mesogondolella clarki*, *M. donbassica*, *M. subclarki*, *Neolochriea glaber*, *Neolochriea nagatoensis* (Igo & Koike, 1965), *Gondolella* sp. and *Idiognathodus* spp. This zone is also recognized in the Naqing section, and can be roughly correlated with the *I. podolskensis* Zone, *N. inaequalis* Zone and *N. roundyi* Zone in Russia, the upper part of the *N. asymmetricus* Zone and the *N. roundyi* Zone in North America (Wang & Qi, 2003; Wang *et al.* 2008).

3.d.4. Swadelina fauna Zone (ZXC 38.4–48.0; Fig. 8)

The base of this Zone is marked by the FAD of any species of *Swadelina*, while its top is marked by the FAD of *Idiognathodus swadei* Rosscoe & Barrick, 2009*a*. This zone is characterized by the appearance of *Swadelina* sp. 2 Barrick, Qi & Wang, 2010 in the Dianzishang section. Other forms in this zone are *Gondolella* spp. and *Idiognathodus* spp. Even though the taxonomy of *Swadelina*, *Idiognathodus* and *Gondolella* from the Moscovian in South China are not fully understood at the species level, the *Swadelina* fauna Zone in the Dianzishang section can be correlated with the beds that yield the latest Moscovian *Swadelina* fauna worldwide (Lambert *et al.* 2003; Wang & Qi, 2007; Barrick *et al.* 2010; Goreva & Alekseev, 2010; Nemyrovska, 2011).

3.d.5. Idiognathodus swadei Zone (ZXC 48.0–65.0; Fig. 9)

The base of this zone, the latest Moscovian zone, is marked by the FAD of *Idiognathodus swadei* and its top is marked by the FAD of *I. turbatus* Rosscoe & Barrick, 2009*a*. Although *I. turbatus*, the greatest-potential boundary marker for the base of global Kasimovian Stage, has not yet been found in the Dianzishang section, the morphology of juveniles of *Idiognathodus* (Fig. 9o–r) from sample ZXC 67.8 indicate a possible early Kasimovian age. We tentatively put the top of this zone at 65.0 m in this section. This zone is also recognized in the Naqing section (K. Y. Hu, unpub. Masters thesis, Graduate University of Chinese Academy of Sciences, 2012), and it can be correlated

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Figure 5. Visean – lower Bashkirian interval in the Dianzishang section, Zhenning, Guizhou, South China. (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, catalogue numbers 155794–155808.) (a) *Lochriea comutata* (Branson & Mehl, 1941) oral view, sample DZSC7.70, cat. no. 155794; (b) *Lochriea saharea* Nemyrovska, Perret & Weyant, 2006, oral view, sample DZSC7.70, cat. no. 155795; (c, d) *Gnathodus praebilineatus* Belka, 1985, oral views, (c), sample DZSC49.00, (d), sample DZSC64.40, cat. no. 155796, 155797; (e) *Lochriea costata* (Pazukhin & Nemirovska in Kulagina *et al*. 1992), oral view, sample DZSC57.80, cat. no. 155798; (f) *Lochriea monocostata* (Pazukhin & Nemirovska in Kulagina *et al*. 1992) oral view, sample DZSC57.80, cat. no. 155799; (g) *Pseudognathodus homopunctatus* (Ziegler, 1960) oral view, sample DZSC7.70, cat. no. 155800; (h) *Gnathodus bilineatus bilineatus* (Roundy, 1926) oral view, sample DZSC57.80, cat. no. 155801; (i) *Declinognathodus noduliferus noduliferus* (Ellison & Graves, 1941) oral view, sample DZSC59.40, cat. no. 155802; (j, k) *Lochriea ziegleri* Nemirovskaya, Perret-Mirouse & Meischer, 1994, oral views, (j), sample DZSC49.00, (k) sample DZSC59.40, cat. no. 155803, 155804; (l) *Gnathodus bilineatus bollandensis* Higgins & Bouckaert, 1968, oral view, sample DZSC59.40, cat. no. 155805; (m) *Gnathodus bilineatus remus* Meischner & Nemyrovska, 1999, oral view, sample DZSC64.40, cat. no. 155806; (n) *Declinognathodus* cf. *lateralis* (Higgins & Bouckaert, 1968) oral view, sample DZSC61.80, cat. no. 155807; (o) *Gnathodus postbilineatus* Nigmadganov & Nemirovskaya, 1992, oral view, sample DZSC61.80, cat. no. 155808.

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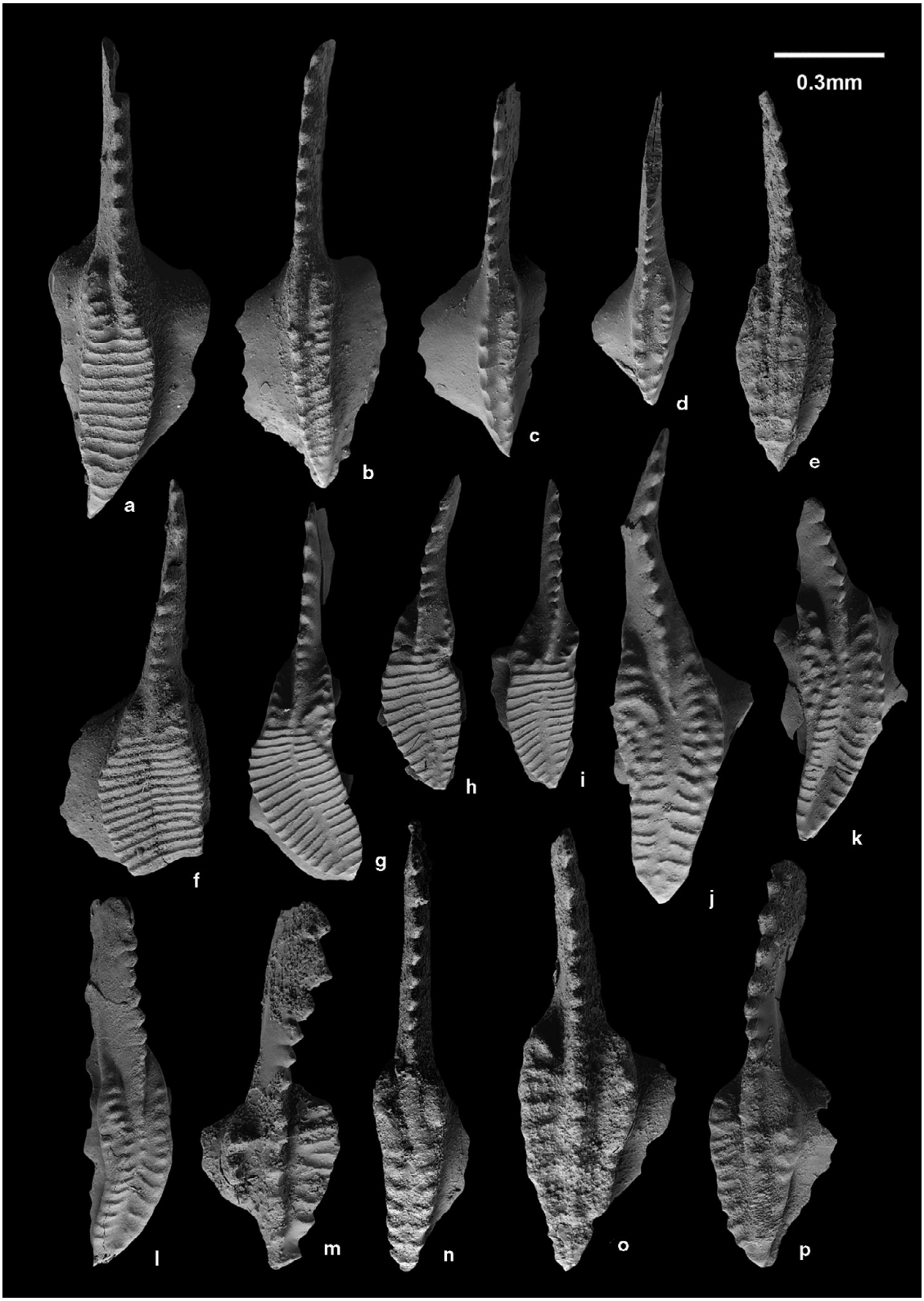

Figure 6. Lower Bashkirian – lower Moscovian interval in the Dianzishang section. (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, catalogue numbers 155809–155824.) (a) *Idiognathoides corrugates* Harris & Hollinsworth, 1933, oral view, sample DZSC61.80, cat. no. 155809; (b) *Idiognathoides sinuatus* Harris & Hollingsworth, 1933, oral view, sample DZSC68.50, cat. no. 155810; (c) *Idiognathoides postsulcatus* Nemyrovska, 1999, oral view, sample ZXC−18.60, cat. no. 155811; (d) *Idiognathoides sulcatus sulcatus* Higgins & Bouckaert, 1968, oral view, sample ZXC−18.60, cat. no. 155812; (e) *Neognathodus symmetricus* (Lane, 1967) oral view, sample ZXC−20.00, cat. no. 155813; (f) '*Streptognathodus*' *expansus* (primitive form) Igo & Koike, 1964, oral view, sample ZXC−16.60, cat. no. 155814; (g–i) '*Streptognathodus*' *expansus* Igo & Koike, 1964, oral views, (g) sample ZXC−11.80, (h, i) sample ZXC−12.10, cat. nos 155815–155817; (j–l) '*Streptognathodus*' *suberectus* Dunn, 1966, oral views, (j) sample ZXC−11.80, (k, l) sample ZXC−12.10, cat. nos 155818–155820; (m) *Neognathodus kanumai* Igo, 1974, oral view, sample ZXC−16.60, cat. no. 155821; (n) *Declinognathodus marginodosus* (Grayson, 1984) oral view, sample ZXC−10.30, cat. no. 155822; (o, p) *Neognathodus bothrops* Merrill, 1972, oral views, (o) sample ZXC−10.30, (p) sample ZXC−8.50, cat. nos 155823, 155824.

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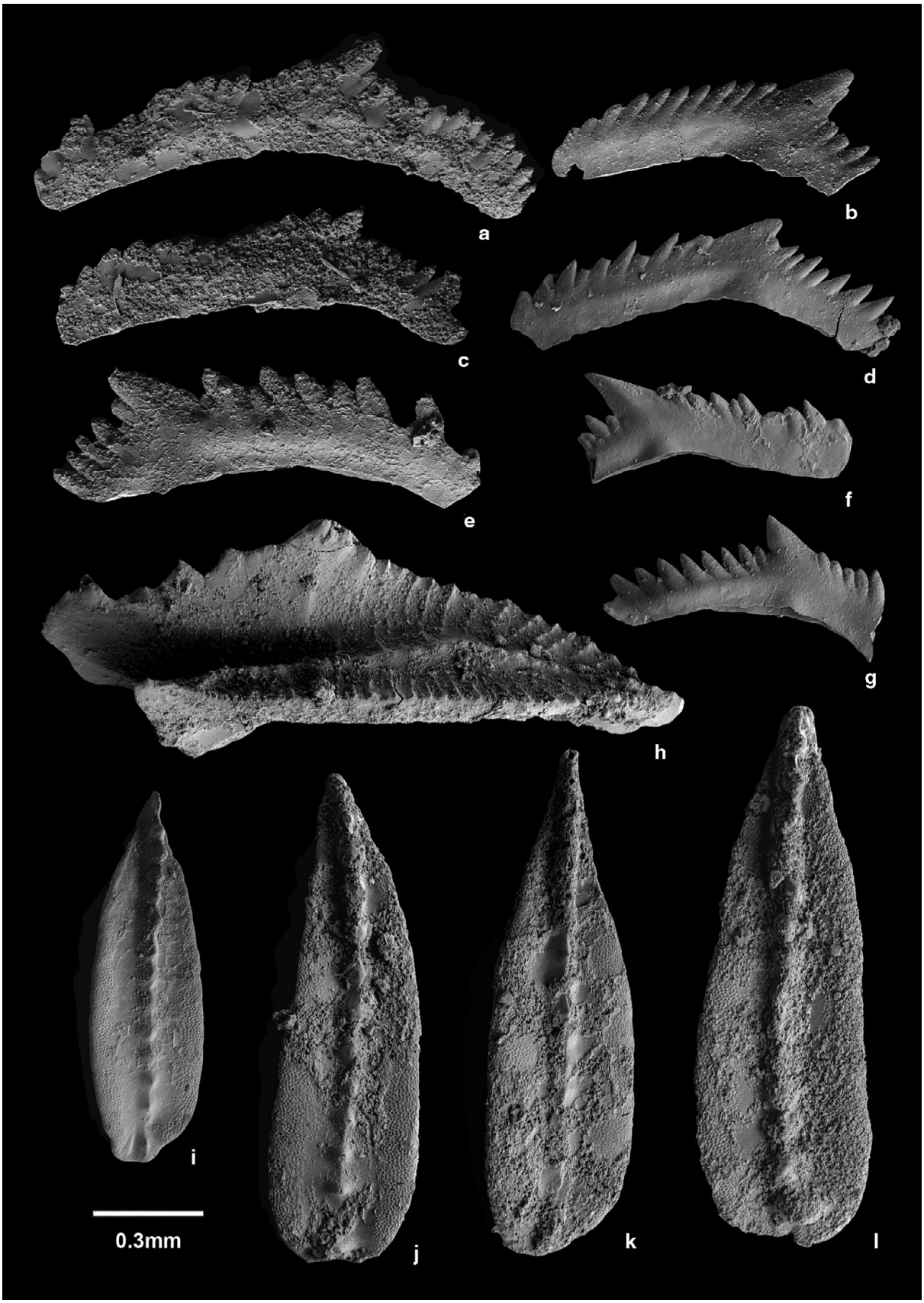

Figure 7. Upper Visean – middle Moscovian interval in the Dianzishang section. (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, catalogue numbers 155825–155836. (a–g) *Gondolella* spp. lateral views, (a, c) sample ZXC−1.30, (b) sample ZXC−5.00, (d, f, g) sample ZXC 28.30, 5, sample ZXC−10.30, cat. nos 155825–155831; (h) *Mestognathodus beckmani* Bischoff, 1957, latero-oral view, sample DZSC42.50, cat. no. 155832; (i, j) *Mesogondolella clarki* (Koike, 1967) oral views, (i), sample ZXC 28.30, (j), sample ZXC−1.30, cat. nos 155833, 155834; (k) *Mesogondolella donbassica* Kossenko, 1975, oral view, sample ZXC−1.30, cat. no. 155835; (l) *Mesogondolella subclarki* Wang & Qi, 2003, oral view, sample ZXC−1.30, cat. no. 155836.

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Figure 8. Lower–upper Moscovian interval in the Dianzishang section. (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, catalogue numbers 155837–155851. (a–f) *Idiognathodus* spp. oral views, (a) sample ZXC−2.60, (b) sample ZXC 20.50, (c) sample ZXC 38.40, (d) sample ZXC 4.00, (e, f) sample ZXC 28.30, cat. nos 155837–155842; (g) *Swadelina* sp. 2 Barrick, Qi & Wang, 2010, oral view, sample ZXC 38.40, cat. no. 155843; (h–j) *Idiognathodus podolskensis* Goreva, 1984, oral views, (h,i), sample ZXC 38.40, (j) sample ZXC 20.50, cat. nos 155844–155846; (k) *Idiognathoides fossatus* (Branson & Mehl, 1941) oral view, sample ZXC−0.20, cat. no. 155847; (l) *Idiognathodus amplificus* Lambert, 1992, oral view, sample ZXC−1.30, cat. no. 155848; (m) *Neognathodus caudatus* Lambert, 1992, oral view, sample ZXC−8.50, cat. no. 155849; (n) *Neolochriea hisaharui* Mizuno, 1997, oral view, sample ZXC−6.00, cat. no 155850; (o) *Neolochriea nagatoensis* (Igo & Koike, 1965) oral view, sample ZXC 4.00, cat. no. 155851.

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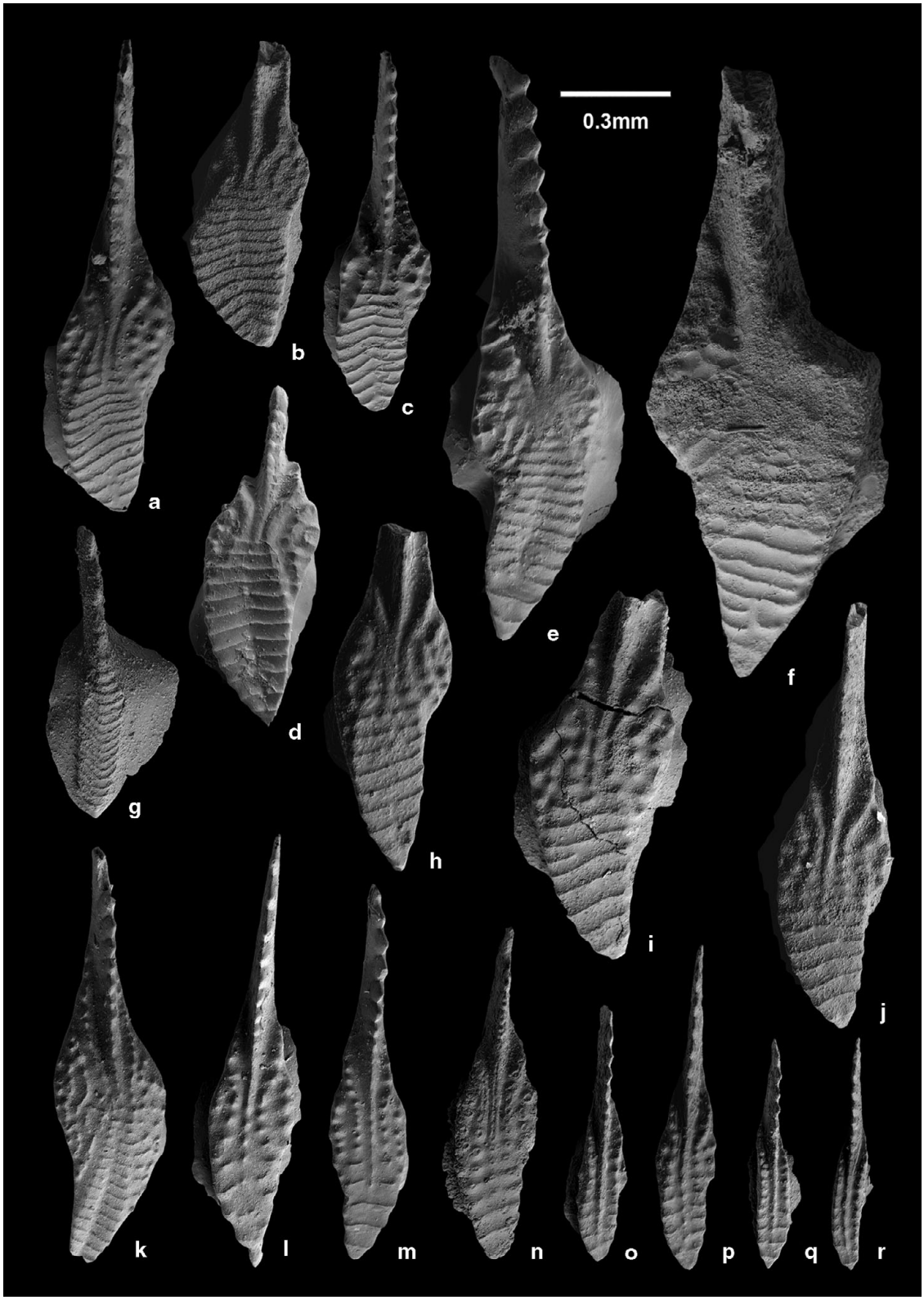

Figure 9. Lower Moscovian – lower Kasimovian interval in the Dianzishang section. (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, catalogue numbers 155852–155869. (a–d) *Idiognathodus* spp. oral views, (a) sample ZXC 31.80, (b) sample ZXC 4.00, (c) sample ZXC 28.30, (d) sample ZXC 20.50, cat. nos 155852–155855; (e) Transitional form from *Idiognathodus praeobliquus* Nemyrovska, Perret-Mirouse & Alekseev, 1999 to *Idiognathodus obliquus* Kossenko in Kozitskaya *et al.* 1978, oral view, sample ZXC 28.30, cat. no. 155856; (f) *Idiognathodus obliquus* Kossenko in Kozitskaya *et al.* 1978, oral view, sample ZXC−0.20, cat. no. 155857; (g) *Idiognathoides planus* Furduj, 1975, oral view, sample ZXC 2.50, cat. no. 155858; (h–j) *Idiognathodus swadei* Rosscoe & Barrick 2009*a*, oral views, sample ZXC 67.80, lower Kasimovian cat. nos 155859–155861; (k) '*Streptognathodus*' *suberectus* Dunn, 1966, oral view, sample ZXC 38.40, cat. no. 155862; (l–n) Transitional forms from *Idiognathodus swadei* Rosscoe & Barrick 2009*a* to *Idiognathodus turbatus* Rosscoe & Barrick 2009*a*, oral views, sample ZXC 48.00, cat. nos 155863–155865; (o–r) *Idiognathodus* juveniles, oral views, sample ZXC 67.80, lower Kasimovian cat. nos 155866–155869.

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with the *Idiognathodus sulciferus* Zone in North America (S. J. Rosscoe, unpub. Ph.D. dissertation, Graduate Faculty of Texas Tech University, 2008) and *I. arendti* Subzone in Russia (Barskov, 1984; Barskov *et al.* 1984; Goreva & Alekseev, 2010).

4. Discussion

4.a. Visean–Serpukhovian boundary

The GSSP of the base of Serpukhovian has not yet been established, but the majority of the boundary Task Group members agree on using the FAD of *Lochriea ziegleri* in the evolutionary lineage *L. nodosa* – *L. ziegler* as the GSSP marker. The species is easy to identify, widely distributed and relatively abundant. These features indisputably indicate that *Lochriea ziegleri* is a perfect boundary marker despite its first occurrence being a little earlier than the traditionally defined Serpukhovian base (Qi, Wang & Luo, 2004, 2010*b*, 2010*c*; Wang & Jin, 2005; Y. P. Qi, unpub. Ph.D. thesis, Graduate University of Chinese Academy of Sciences, 2008). In the Dianzishang section, the first occurrence of *Lochriea ziegleri* is at 49.0 m in the lower part of the section (the Xiaoxibian section), which indicates the Visean–Serpukhovian boundary. Unfortunately, *Lochriea nodosa*, the ancestor of *L. ziegleri*, has not yet been found in this section.

4.b. Serpukhovian–Bashkirian boundary

The GSSP of the base of Bashkirian was established in 1996 in the Arrow Canyon section, Nevada, USA. The FAD of conodont species *Declinognathodus noduliferus* was selected as the marker of this boundary (Lane *et al.* 1999). In the Dianzishang section, the base of the Bashkirian lies at the first occurrence of *Declinognathodus noduliferus noduliferus* at 59.4 m of the lower part of the section (the Xiaoxibian section)

4.c. Bashkirian–Moscovian boundary

Presently, the definition of the base of Moscovian is still in dispute. Three candidates for the marker of this boundary have been proposed by the boundary Task Group (Groves & Task Group, 2006): (1) the FAD of *Declinognathodus donetzianus* in the evolutionary lineage of *Decl. marginodosus* (Grayson) – *Decl. donetzianus* Nemirovska, 1990; (2) the FAD of *Idiognathoides postsulcatus* in the evolutionary lineage *Id. sulcatus sulcatus* Higgins & Bouckaert, 1968 – *Id. postsulcatus* Nemyrovska, 1999; and (3) the FAD of one of the members of the evolutionary lineage from primitive to advanced forms of *Neognathodus nataliae*. These candidates all have their limitations for the recognition of the Bashkirian–Moscovian boundary worldwide according to detailed studies of the conodonts in the Naqing section. A new candidate taxon has therefore been proposed: the FAD of *Diplognathodus ellesmerensis* (Qi *et al.* 2007, 2009, 2010*a*; Y. P. Qi, unpub. Ph.D. thesis, Graduate University of Chinese Academy of Sciences, 2008; Wang *et al.* 2008, 2011). The FAD of *Diplognathodus ellesmerensis* is very near a previously defined Moscovian base (the FAD of *Declinognathodus donetzianus*, Alekseev & Goreva, 2000). Because it is widely distributed and easy to identify, *D. ellesmerensis* should be a very suitable boundary marker. However, it is not easily recovered due to its small size. Furthermore, the evolutionary lineage of this species is not very clear and requires further investigation. These imperfections led to a dispute on the proposal to use *D. ellesmerensis* as the boundary marker (Groves & Task Group, 2008). Recently, on the basis of detailed studies on conodonts in the Bashkirian–Moscovian boundary interval in South China, a new conodont evolutionary lineage (from primitive form to advanced form in *Streptognathodus expansus*) was found (Qi *et al.* 2010*a*). *Streptognathodus expansus* was named by Japanese conodont workers in 1964 (Igo & Koike, 1964). According to the description and illustrations, the originally published specimens belong to the advanced form of this species. The newly discovered primitive form may need a new species/subspecies name. In the Naqing section, the FAD of *Streptognathodus expansus* is near the top of Bashkirian, 5.25 m lower than the FAD of *Diplognathodus ellesmerensis*. Compared to *Diplognathodus ellesmerensis*, *Streptognathodus expansus* is larger, more abundant and also widely distributed. Its lineage is very clear and easy to identify. This species might be an excellent candidate for the marker of the base of Moscovian (Qi *et al.* 2010*a*, 2011). In this paper, the Bashkirian–Moscovian boundary is recognized at –12.0 m of the lower part of the section (the Dalubian section), which coincides with the FAD of *Streptognathodus expansus*.

4.d. Moscovian–Kasimovian boundary

The Working Group on the Moscovian–Kasimovian boundary proposed two potential biostratigraphic markers, *Idiognathodus sagittalis* Kozitskaya, 1978 in Kozitskaya *et al.* 1978 and *Idiognathodus turbatus* Rosscoe & Barrick, 2009*a*, by which the base of the Kasimovian Stage can be marked and correlated globally (Ueno & Task Group, 2009). *Idiognathodus sagittalis* is based on material from the Donets Basin (Ukraine) and *I. turbatus* is based on material from mid-continent North America. A lineage from *Idiognathodus swadei* Rosscoe & Barrick, 2009*a* to *I. turbatus* has been described from mid-continent North America (Rosscoe & Barrick, 2009*b*). Highly abundant conodonts have been recovered from the large collections of the Moscovian–Kasimovian boundary interval in the Naqing section, Guizhou of South China in recent years, among which many transitional morphotypes (similar to *I. sagittalis*) with rapid morphological transformation from *I. swadei* to *I. turbatus* are found. The important conodont evolutionary lineage from

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I. swadei to *I. turbatus* is therefore also confirmed in South China.

In the Moscow Basin, Goreva *et al*. (2009, fig. 6L) illustrated a specimen as *Idiognathodus turbatus* that is similar to *I. turbatus* from the Naqing section. Their *I. sagittalis*, which occurs below *I. turbatus*, resembles the *I. swadei – I. turbatus* transitional forms from the Naqing section. Possibly, *I. sagittalis* may be the transitional form from *I. swadei* to *I. turbatus*. The FAD of *I. turbatus* in the *I. swadei – I. turbatus* lineage appears to be the only reasonable biostratigraphic marker for defining the Moscovian–Kasimovian boundary. Unfortunately, *I. turbatus* has not yet been found in the Dianzishang section, but several transitional forms (Fig. 9l–n) from *I. swadei* to *I. turbatus* were found in the upper part of this section and *Idiognathodus* juveniles (Fig. 5o–r) from sample ZXC 67.8 appear to be possible early Kasimovian morphotypes. We therefore tentatively put the Moscovian–Kasimovian boundary at a level of 65.0 m in the Dianzishang section.

5. Conclusion

The Dianzishang section is intermediate between the lower-slope to basin deposits at Naqing and the shallow-marine platform deposits at Yashui (Richards & Task Group, 2010). Abundant conodonts and foraminifers are found in this section. The preliminary conodont succession including only 11 conodont zones and conodont biostratigraphy from lower Visean to uppermost Moscovian are summarized here, which are based on very coarse sampling of the section during the past few years. Additional sampling at finer stratigraphic intervals with larger sample sizes are therefore needed for a more detailed investigation. Studies on foraminiferal biostratigraphy and its correlation with conodont biostratigraphy are badly needed for accurate correlations between shallow-marine and deep-marine sections worldwide.

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