Permian fusulinid biostratigraphy of the Baoshan Block in western Yunnan, China with constraints on paleogeography and paleoclimate

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Abstract
Newly obtained fossil materials together with published data enable a review on the Permian fusulinids of the Gondwana-derived Baoshan Block in western Yunnan, China. The Baoshan Block yields rather impoverish Sakmarian–Yakhtashian fusulinids with just Eoparafusulina and Pseudofusulina in its northern and southern parts. These fusulinids biogeographically demonstrate the feature of peri-Gondwana province and signify a temperate-water condition. Further comparison suggests the Baoshan Block was located distant from the tropical region and even with higher latitude than Central Iran and Central Pamir during the Sakmarian–Yakhtashian. In contrast, Murgabian–Midian fusulinids are more diversified. In the southern Baoshan Block, the Schwagerina assemblage, the Eopolydiexodina assemblage, the Sumatrina assemblage and the Verbeekina assemblage could be recognized in the Xiaoxinzhai area, and the Yangchienia–Nankinella assemblage and the Chusenella–Rugosofusulina assemblage in the Bawei area, in ascending order. Contemporaneously, the Neofusulinella assemblage occurs in the northern and the Eopolydiexodina assemblage in the southwestern Baoshan Block respectively. These Murgabian–Midian fusulinids show affinity of western Tethyan province and suggest a warm-water environment. Interestingly, the Midian Verbeekina assemblage is characterized by relatively low diversity and rather abundance of just one genus. Such compositional feature most likely signifies warm but still not optimal sea-surface water for the diversification of fusulinids. Also taking into account of the presence of Verbeekinids and Neoschwagerinids and the moderate total diversity, the Middle Permian fusulinids indicate that the Baoshan Block, during the Murgabian–Midian, was probably located between equatorial region with warm water to the north and the majority of Sibumasu areas lacking Verbeekinids and Neoschwagerinids with temperate water to the south.

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1. Introduction

Spatio-temporal variation of fusulinid assemblages during the Permo-Carboniferous not only is valuable for stratigraphic correlation, but also record unique information for paleogeographic and paleoclimatic analysis. Such significant usefulness of fusulinids has been especially demonstrated in reconstructing the geological evolution of small terranes which have accreted to large crustal continents, e.g. Cimmerian continents derived from the northern Gondwana and exotic terranes in the Circum-Pacific, as these small terranes oftentimes have experienced a highly dynamic paleogeographic evolution and lack reliable paleomagnetic data (Newton, 1988; Smith and Xu, 1988; Kobayashi, 1997a,b, 1999; Belasky et al., 2002; Vachard et al., 2002; Ueno, 2003; Davydov and Areffard, 2007; Huang et al., 2009; Leven, 2009; Davydov et al., 2013; Zhang et al., 2013).

The Baoshan Block in western Yunnan, Southwest China represents such a continental block. It is generally believed to have been located at the northern margin of Gondwana at high latitude in Early Permian, then drifted northwards toward low latitude after rifted from Gondwana, and finally docked to the Eurasian continent (Jin, 1994; Shi and Archbold, 1998; Metcalfe, 2002). Meanwhile, global climate has been suggested to change from icehouse to greenhouse during the Permian period (Rees et al., 1999; Scotese et al., 1999; Shi and Waterhouse, 2010). The coupled effects of such paleogeographic and paleoclimatic scenarios would be expected to prompt compositional transition of the environment-sensitive fusulinids in the Baoshan Block. Thus, inspecting
these fusulinids could offer insights for better understanding the paleogeographic evolution of this block, which is in turn indispensable for the Gondwana dispersion and Asian accretion.

Since the 1980s, many efforts have been devoted to report or systematically describe the Permian fusulinids of the Baoshan Block and further address their paleogeographic and paleoclimatic significance (e.g. Duan et al., 1983; Yang, 1983; Chen, 1984; Sugiyama and Ueno, 1998; Fang et al., 2000; Ueno, 2003; Huang et al., 2009; Shi et al., 2011). However, the paleoclimatic meaning of these fusulinids has not been fully disclosed and the exact paleogeographic position of the Baoshan Block in relation to other Gondwana-derived blocks has been still controversial (Metcalfe, 2002; Ueno, 2003; Huang et al., 2009; Wopfner and Jin, 2009; Ali et al., 2013; Zhang et al., 2013). Solving these issues is partially hindered by the inadequacy of solid fossil materials, especially Middle Permian fusulinids. We have recently measured a new section with abundant Middle Permian fusulinids, discovered a Verbeekina assemblage with usual taxonomic features and a Neoschwagerina assemblage in the Baoshan Block. These newly obtained fossils together with published data in literate enable a review in this paper on taxonomic composition and biostratigraphic succession of the Permian fusulinids in the Baoshan Block. Furthermore, we compare these fusulinids of the Baoshan Block with those from equatorial region and other Gondwana-derived blocks. By doing that, we are able to refine the paleobiogeographic affinity and paleoclimatic implications of these fusulinids, and calibrate the paleogeographic position of the Baoshan Block.

2. Geological background

According to the development of Permo-Carboniferous stratigraphy, the Baoshan Block has been divided into three subdivisions (Fig. 1) (Jin, 1994). The Permian lithological sequences are generally consistent in its northern, southern and southwestern subdivisions, although varying names of lithological formations have been applied (Fig. 2) (Wang et al., 2002; Jin et al., 2008). The Lower Permian is mainly composed of siliciclastic deposits followed by basalts, while the Middle and Upper Permian is majorly carbonate sediments. The lowest siliciclastic deposits in the northern and southern Baoshan Block are named Dingjiazhai Formation. This formation represents a transgressive sequence and consists of sandstone, siltstone, mudstone, with limestone in its top part. Probable glaciogenic diamicites with poorly sorted and angular pebbles in fine siliciclastic matrix are characteristic in the lower part of this formation in the northern Baoshan Block, but rather poorly developed in the southern subdivision (Jin, 1994, 2002). Fossils in this formation, such as brachiopods, corals and spores and pollens, show features of cool water and Gondwana affinity (Fang, 1994; Fang and Fan, 1994; Shi et al., 1996; Gao, 1998; Fang et al., 2000; Wang et al., 2001). These diamicites and cool-water fossils are the main evidence to relocate the Baoshan Block in the northern margin of Gondwana in the Early Permian (Wang, 1983; Jin, 1994; Wopfner, 1996; Metcalfe, 2002). Taxonomically poor fusulinids occur in the limestones of the top Dingjiazhai Formation. The basalts of the Woniusi Formation overlie the Dingjiazhai Formation and may signify the rift of this block from the Gondwana (Wopfner, 1996; Shi and Archbold, 1998). Either the Dingjiazhai Formation or the Woniusi Formation is absent in the southwestern Baoshan Block. A short hiatus may exist after the eruption of the basalts, because hard ground is observed at the top of the Woniusi Formation at some outcrops. Above these basalts, variegated siliciclastic sediments steadily occur throughout the Baoshan Block and represent the beginning of a new transgression, although they have been named the Manli Formation in the southwestern subdivision, the Bingma Formation in the northern subdivision and the lower part of the Yongde Formation in the southern subdivision (Geological Survey Team of Yunnan, hereafter as GSTY, 1966, 1980, 1984). Upwards, the carbonate sequences are initially composed of argillaceous limestone and limestone which are subsequently overlain by dolomitic limestone to dolomite. The argillaceous limestone is considered upper part of the Yongde Formation in the southern subdivision, and together with limestone is grouped into the Daozi Formation in the northern subdivision. The limestone and dolomitic limestone to dolomite are grouped into the Shazipo Formation in the southern and southwestern subdivisions, while the dolomitic limestone to dolomite is named a separate Hewanjie Formation in the northern subdivision. A marked difference is that the limestone portion is considerable thicker and more fossiliferous in the southern than in the northern, and southwestern Baoshan Block. Fusulinids occur in both the argillaceous limestones and limestones in the lower part of carbonate sequence throughout the Baoshan Block. In the northern and southwestern subdivisions, the dolomitic limestones to dolomites are oftentimes severely brecciated in fields and thus referred to as “Cracked limestone”, whereas they are less broken in the southern subdivision. A particular foraminiferal Shanita fauna occurs in these dolomitic limestones across the Baoshan Block (Sheng and He, 1983; Yang et al., 2004; Huang et al., 2007). This fauna is thought to be Midian to early Dhulfanian and geographically confined in blocks of Gondwana-origin (Huang et al., 2007; Ueno, 2003; Jin and Yang, 2004).

3. Fusulinid biostratigraphy

For the Permian chronostratigraphy, the traditional Tethyan scale (Leven, 2004), instead of the international standard of Jin et al. (1997), is used in this paper. The main reason is that the Permian Tethyan scale is defined by the evolutionary events of fusulinids, thus readily applied across the Tethyan realm. However, the international Permian stages, especially the Guadalupian ones, are based on conodonts from North America, and their recognition and precise correlation in the Tethyan region have not been solved so far with satisfaction (Leven, 2001; Leven and Bogoslovskaya, 2006). For convenience, the Asselian–Bolorian interval in the Tethyan scale is treated as Early Permian and Kubergandian–Midian interval is treated as Middle Permian hereinafter.

3.1. Early Permian

Early Permian fusulinids with similar composition firstly appear in the limestones in the top part of the Dingjiazhai Formation in both northern and southern Baoshan Block (Figs. 1 and 3). The southwestern Baoshan Block is devoid of Early Permian sedimentary records (Fig. 2). The fusulinids in the Dingjiazhai Formation were previously regarded to be dominated by Triticites with Eoparafusulina, Hemifusulina, and Schwagerina in association, and thus correlated to the Late Carboniferous Triticites zone (Duan et al., 1983; Yang, 1983; Chen, 1984; GSTY, 1980, 1984, 1985; Bureau, 1990). Unfortunately, these early studies did not provide illustration or description, which render the verification of the identification impossible. The dating of these fusulinids has been rectified to Early Permian by recent studies (Sugiyama and Ueno, 1998; Fang et al., 2000; Ueno, 2003; Shi et al., 2011). Sugiyama and Ueno (1998) and Ueno (2003) identified and illustrated these fusulinids as Eoparafusulina and Pseudofusulina from Dongshanpo Section and Woniusi Section in the northern Baoshan Block. Fang et al. (2000) systematically restudied the fusulinids from the top part of the Dingjiazhai Formation and considered them to be dominated by Eoparafusulina and Schwagerina with only a few Triticites. Shi et al. (2011) suggested that fusulinids in the top part of the Ding-
The Dingjiazhai Formation contained only two genera *Eoparafusulina* and *Pseudofusulina*, based on materials from Dongshanpo Section (Locality 8 in Fig. 1) in the northern Baoshan Block and Aluotian Section (Locality 11 in Fig. 1) in the southern Baoshan Block. Shi et al. (2011) reallocated the specimens of *Schwagerina* and *Triticites* in the paper of Fang et al. (2000) under *Eoparafusulina*, because these specimens demonstrate cuniculi structure and fail to exhibit strong chomata as typical *Triticites* do or tight inner to loose outer coiling which characterizes *Schwagerina*.

According to the results of Shi et al. (2011), the fusulinids in the top part of the Dingjiazhai Formation from the Dongshanpo Section consist of two species: *Pseudofusulina macilenta* Leven (1993) and *Eoparafusulina pseudosimplex* (Chen, 1934), while those from the Aluotian Section are relatively more diverse, including *P. minutumidiscula* Shi et al. (2011), *P. macilenta*, *P. tumidiscula* Shi et al. (2011), *P. macilenta* var. *laudoni* Leven (1993) and *E. aff. laudoni* Leven (1993) and *E. sp.* (Fig. 4). The composition of these fusulinids is distinct in two respects: rather low taxonomic diversity and abundant individuals that locally form fusulinid limestones (Fig. 5). Judging from these features, they are well comparable to the Early Permian fusulinid assemblages from other Gondwana-derived blocks, such as Posht-e-Badam Block in East-Central Iran, Tengchong Block in western Yunnan of China, South Qiangtang Block in Tibet, Central Pamir, Central Oman, South Afghanistan, East Hindu Kush, Karakorum and Sibumasu region (Leven, 1993; Davydov and Arefifard, 2007). Most species under consideration (e.g. *Pseudofusulina macilenta*, *P. tumidiscula*, *P. minutumidiscula* and *Eoparafusulina aff. laudoni*) have been previously reported from these areas in Early Permian beds, which were dated.

**Fig. 1.** Geographic map of the Baoshan Block in western Yunnan, China, showing the main localities of Permian fusulinids. 1 Sanjiazhai, 2 Xinzhai and Longtang, 3 Langba, 4 Wonusi and Daozi, 5 Moshikan, 6 Ama Hill, 7 Laonanwo, 8 Dongjiazhai and Dongshanpo, 9 Nongkian, 10 Zhelfang, 11 Aluotian and Tizipo, 12 Taozizhai, 13 Anpaitian, 14 Fengwei, 15 Baweili, 16 Mingxin, 17 Nansan and 18 Xiaoxinzhai.
Sakmarian or late Sakmarian–Early Artinskian in age (Leven, 1993, 1997; Gaetani and Leven, 1993; Gaetani et al., 1995; Angiolini et al., 2006; Davydov and Arefifard, 2007). Besides, spores and pollen below the fusulinid-bearing level in the Dingjiazhai Formation are indicative of Asselian to early Sakmarian age (Gao, 1998; Fang et al., 2000); conodonts from the limestones in the top Dingjiazhai Formation suggest a late Sakmarian to middle Artinskian age (Ueno et al., 2002; Zhao, 2003; Wang et al., 2004; Ji et al., 2004). According to Leven and Bogoslovskaya (2006), the Artinskian stage in the international scale corresponds to the Yakhtashian stage in the Tethyan scale on the basis of ammonoids and conodonts. Therefore, the fusulinids from the Dingjiazhai Formation in the Baoshan Block are considered to be late Sakmarian to Yakhtashian in age (Fang et al., 2000; Shi et al., 2011).

In addition, a potentially new genus of Boultoniidae with expanded final whorl and changing direction of coiling axis through ontogeny has been illustrated from the top part of Dingjiazhai Formation of the Dongshanpo Section (Sugiyama and Ueno, 1998, plate 1, Fig. 8; Wang et al., 2001, plate 3, fig. P). Monodiexodina has been mentioned without illustration from the top part of the Dingjiazhai Formation in Ama Hill near Jinji Village (Locality 6 in Fig. 1) (GSTY, 1980). The occurrence of Monodiexodina is highly questionable, as it has never been reported anywhere else and not encountered in our field works.

Fusulinids have also been reported, but not figured from the carbonate intercalations in the basalts of the Woniusi Formation and previously identified as Triticites, Eoparafusulina, Quasifusulina, Hemifusulina and Schwagerina (GSTY, 1980, 1985; Duan et al., 1983; Bureau, 1990). The only exception is that Duan et al. (1983, pl. II, Figs. 7 and 8) illustrated Triticites parvulus (Schellwien, 1909) from the Woniusi Formation near Jinji Village (Locality 4 in Fig. 1).
According to the figures, these specimens of *T. parvulus* have very small ellipsoidal test and weak chomata, thus probably are immature specimens of *Eoparafusulina*. In general, the taxonomic list of the fusulinids in the Woniusi Formation is essentially identical with that from the top part of the Dingjiazhai Formation in these early literatures. We, thus, doubt that most fusulinids specimens in the limestones intercalated in the Woniusi Formation could also be reassigned to either *Eoparafusulina* or *Pseudofusulina*, although no other figures or fossils are accessible for reexamination.

3.2. Middle Permian

Middle Permian fusulinids occur across the Baoshan Block, but are more diverse and abundant in the southern part. The cause for such an uneven distribution seems to be that limestones are much thicker in the southern Baoshan Block; whereas dolomitic limestones occupy the majority of the carbonate sequence in the northern and southwestern areas (Fig. 2). In the northern Baoshan Block, Middle Permian fusulinids have mainly been reported from the Jinji Village in the vicinity of the Baoshan City (Locality 3 in Fig. 1) (GSTY, 1980; Zhou et al., 2000; Ueno, 2001). For instance, GSTY (1980) reported Nankinella, Schwagerina and *Leelia* without giving any illustration, from the bioclastic limestones in the lower part of the Daaozi Formation. These fusulinids are dated to be Chadian (approximately Bolorian–early Murgabian) in terms of Chinese chronology (GSTY, 1980). Zhou et al. (2000) reported and illustrated *Neofusulinella lantenoisi*, Nankinella sp. and *Staffella* sp. from the lower part of the Daaozi Formation. Ueno (2001) studied and illustrated Nankinella, Staffella and *Jinzhangia* also in the Daaozi Formation and assigned these fusulinids to be Murgabian in age, mainly based on the occurrence of coral *Wentzellophyllum persicum* in this formation. When establishing the *Jinzhangia* as a new genus, Ueno (2001) argued that this new genus differs from *Neofusulinella* by “having a replaced shell and lacking an endothyroid-like juvenile”. This new genus is considered in this paper synonymous with *Neofusulinella*, because Zhou and Sheng (1994) concluded that *Neofusulinella* has a primary four-layered spirotheca which are oftentimes recrystallized and with essentially straight coiling axis. Besides, Duan et al. (1983) illustrated some specimens of *Paraverbeekina* from the lower part of the carbonates in the Woniusi Section. These figures of *Paraverbeekina* closely resemble *Neofusulinella* and fail to show distinct parachomata. Therefore, this “*Paraverbeekina*” is also tentatively considered *Neofusulinella* by us unless the structure of spirotheca and parachomata could be confirmed. The presence of fusulinids in the Daaozi Formation in the northern Baoshan Block is certain, although their composition and precise age require future detailed taxonomic work. The brachiopods also from the lower part of the Daaozi Formation suggest a Roadian–Wordian (approximately Murgabian) age (Shi and Shen, 2001; Jin and Zhan, 2008).

In the southwestern Baoshan Block, Middle Permian fusulinids occur with abundant smaller foraminifera in the lower part of the Shazipo Formation. To date, *Polydiexodina* and *Millerella* have been reported without illustration from Nongkan section near Luxi City (Locality 9 in Fig. 1) and *Cancellina* near Zhefang Town (Locality 10 in Fig. 1) (GSTY, 1966). According to our investigation, the specimens of *Polydiexodina* previously identified in the Baoshan Block possess no clear median tunnel and thus should be reassigned to *Eopolydiexodina*. The genus *Eopolydiexodina* is common in Murgabian–Midian sediments, but firstly appears in the Kurgandyian (Leven, 2004).

In the southern Baoshan Block, Middle Permian fusulinids have been reported from several places, e.g. *Nankinella*, *Pseudofusulina*, Schwagerina and *Misellina* from Mingxin Section and Anpaitian area (Locality 17 and 13 in Fig. 1); Schubertella, Ozoumiella, *Misellina* and *Pseudofusulina* from the Fengwei area (Locality 14 in Fig. 1) (Duan et al., 1983; GSTY, 1984, 1985). The taxonomic identification...
of these fusulinids cannot be verified, as no concrete figures have been provided. Ueno (2003) illustrated *Eopolydiexodina* and *Rugosorschwagerina* from the Xiaoxinzhai area. Shi et al. (2005) argued that the specimens previously identified as *Rusgoschwagerina* in the Xiaoxinzhai area should be named a new genus *Xiaoxinzhaiella*, because these specimens have unfluted septa in juvenarium and the juvenile morphology is of phylogenetic significance.

Our field works in recent years in the southern Baoshan Block have revealed to a greater degree the composition of the Middle Permian fusulinids in this region. We have measured two sections with abundant fusulinids in Xiaoxinzhai area (Locality 18 in Fig. 1) and Bawei area (Locality 15 in Fig. 1) respectively, and further found *Neoschwagerina* from the Nansan area (Locality 17 in Fig. 1).

### 3.2.1. Xiaoxinzhai area

The Shazipo Formation with abundant fusulinids is exposed near Xiaoxinzhai Village which is about 50 km northwest to the Gengma Town (Locality 18 in Fig. 1). We have measured a continuous section of the lower part of the Shazipo Formation at the Xiaoxinzhai Village and established three biozones in ascending order: *Schwagerina yunnanensis* Range Zone, *Eopolydiexodina* Abundance Zone and *Sumatrina annae* Range Zone (Fig. 6) (Huang et al., 2009). Moreover, a *Verbeekina* assemblage was recently found a short distance above the top of the measured Xiaoxinzhai Section (Huang et al., in press). Altogether, these four fusulinid assemblages comprise 12 genera, i.e. *Chusenella*, *Schwagerina*, *Parafusulina*, *Verbeekina*, *Pseudodoliolina*, *Xiaoxinzhaiella*, *Armenina*, *Eopolydiexodina*, *Sumatrina*, *Neofusulinella*, *Yangchienia* and *Rugosochnesuella* (Fig. 7).

The *Schwagerina yunnanensis* zone is dominated by abundant and diverse *Schwagerina* and *Chusenella*, accompanied by *Verbeekina* and *Pseudodoliolina*. Species of *Verbeekina* and *Pseudodoliolina* in this zone are significant for biostratigraphic correlation. *Verbeekina grabaui* Thompson and Foster, 1937, V. americana Thompson

![Fig. 6. Distribution of Middle Permian fusulinids in the Xiaoxinzhai Section of the southern Baoshan Block in western Yunnan, China. Inset figure shows the stratigraphic level of the measured Xiaoxinzhai Section in the Shazipo Formation (modified from Huang et al., 2009).](image-url)
et al., 1950, Pseudodoliolina pulchra Sheng, 1963 and P. chinghaiensis Sheng, 1958 are all common elements in the Neoschwagerina zone to Yabeina zone in varying localities, such as South China, Tibet, America, Afghanistan (e.g. Thompson and Foster, 1937; Chen, 1956; Sheng, 1958, 1963; Xiao et al., 1986; Leven, 1997). Meanwhile, this Schwagerina yunnanensis zone is devoid of typical Midian genera, e.g. Yabeina, Lepidolina, Lantschichites, Dunbaruna et al. (Leven, 2004). All these data suggest that the present zone is Murgabian in age (Huang et al., 2009).

The Eopolydiexodina zone can be easily recognized by rather abundant specimens of Eopolydiexodina, whereas the associated genera (Chusenella, Armenina and Xiaoxinzhaiella) are impoverished. E. darwasica (Dutkevitch, 1939) in this zone has been reported from Kubergandian to Murgabian strata in Afghanistan, Turkey, and Darvas region in Tajikistan (Dutkevitch, 1939; Kahler and Kahler, 1979; Leven and Okay, 1996; Leven, 1997), while E. afghanensis (Thompson, 1946) from Murgabian–Midian strata of Afghanistan and Xinjiang in China (Da, 1985; Leven, 1997). Therefore, this zone is also considered to be Murgabian in age (Huang et al., 2009).

Upwards, a distinct compositional change of fusulinid assemblages is observed. In the previous two biozones, fusulinids are dominated by Schwagerinids, whereas in the overlying two assemblages, Verbeekinids and Neoschwagerinids take over the predominance. In the Sumatrina annae zone, Sumatrina and Pseudodoliolina are more diverse than Eopolydiexodina. Sumatrina longissima Deprat...
in this zone are typical Midian species and characteristic in the Yabeina zone of South China, Japan and Iran (Douglas, 1950; Chen, 1956; Sheng, 1956; Toriyama, 1958; Ueno, 1996), although it also occurs in the Neoschwagerina zone in China (Sheng, 1963; Zhang, 1982). S. annae Volz (1904) has a longer stratigraphic range from Murgabian to Midian in Japan, China and Turkey (Ozawa, 1925; Chen, 1956; Kahler and Kahler, 1979; Xiao et al., 1986; Leven, 1997; Kobayashi and Ishii, 2003). The co-occurrence of these two species implies that the age of the present zone is most likely Midian (Huang et al., 2009).

The Verbeekina assemblage (11 species of six genera) bears two unusual compositional features. One is the overwhelming abundance (Fig. 8) of Verbeekina; the other is the relatively lower total diversity, compared with coeval fusulinids from the tropical setting (Huang et al., in press). This assemblage comprises Verbeekina verbeeki (Geinitz and von der Marck, 1876), V. americana, V. aff. americana, V. sp., Pseudodolomitina pseudolepida (Deprat, 1912), P. cylindrical Skinner and Wilde, 1966, Sumatrina annae brevis Leven, 1967, S. aff. annae minima Nie and Song, 1983, Xiaoinizhainella subrotunda Huang, 2010, ?Rugosochusenella sp., Yangchienia sp. indet. Among them, Verbeekina verbeeki is diagnostic of the Murgabian–Midian strata in the Tethyan region (Thompson, 1936; Sheng, 1963; Skinner and Wilde, 1966; Leven, 1967; Toriyama, 1975; Kahler and Kahler, 1979; Kotlyar et al., 1999; Kobayashi, 2011). V. americana was firstly reported in the Verbeekina-Neoschwagerina zone from the Tethyan terranes in the northwest America (Thompson et al., 1950) and later found in Murgabian–Midian limestones of north Afghanistan (Leven, 1997). In addition, Pseudodolomitina pseudolepida has been widely found in the Neoschwagerina zone to Yabeina zone in South China, Turkey, Thailand and Japan (Thompson and Foster, 1937; Hanzawa and Murata, 1963; Sheng, 1963; Kahler and Kahler, 1979; Toriyama and Kanmera, 1977, 1979; Ueno, 1996). Also taking account of its stratigraphic position higher than the Sumatrina zone, this assemblage is preferred to be Midian in age (Huang et al., in press).

### 3.2.2. Bawei area

The Bawei section has been measured from the siliciclastic deposits of the Yongde Formation to the dolomitic limestone of the Shazipo Formation at the Bawei Village of Minglang Town (Locality 15 in Fig. 1). This section provides a good auxiliary sequence for Middle Permian fusulinid biostratigraphy in the southern Baoshan Block. Samples containing abundant fusulinids have been recovered from 17 levels from the limestones and dolomitic limestones of the lower part of the Shazipo Formation. From these samples, 31 species of 11 genera have been systematically studied (Fig. 9). The identified genera are Yangchienia, Afghanella, Nankinella, Neofusulinella, Staffella, Xiaoinizhainella, Chusenella, Kahlerina, Rugosochusenella, Schwagerina and Rugosofusulina (Fig. 10).

Two fusulinid biozones, i.e. Yangchienia–Nankinella Assemblage Zone and Chusenella–Rugosofusulina Assemblage Zone have been recognized in the Bawei Section in ascending order. The former zone is characterized by the association of Yangchienia, Nankinella and Neofusulinella. Y. thompsoni Skinner and Wilde, 1966 in this zone can be found in Maokouan (approximately late Murgabian–Midian) sediments of Tibet and Qinghai in China (Sheng and Sun, 1975; Nie and Song, 1983). Murgabian deposits of Thailand and Iran (Toriyama, 1975; Kobayashi and Ishii, 2003), Midian strata in south Afghanistan, Transcaucasus and Crimea (Kotlyar et al., 1999, 1999; Leven, 1997). Y. haydeni Thompson, 1946 occurs in Maokouan strata of Qinghai, Xingjiang and South China (Sheng, 1963; Sheng and Sun, 1975; Sun and Zhang, 1985; Xiao et al., 1986), also in Murgabian–Midian strata of Afghanistan, central Iran, Crimea and Thailand (Lys and Lapparent, 1971; Toriyama, 1975; Leven, 1997; Kotlyar et al., 1999; Kobayashi and Ishii, 2003). Although Kahlerina in this zone has been regarded as diagnostic for the Midian stage (Leven, 1996, 2004), it also occurs in the Murgabian sediments of South China, Japan and Peri-Mediterranean areas (Sheng, 1963; Vachard and Miconnet, 1989; Kobayashi, 2011, 2012). All these lines of evidence suggest that the Yangchienia–Nankinella zone is Murgabian–Midian in age.

The composition markedly changes into the overlying Chusenella–Rugosofusulina Assemblage Zone. This zone is represented by the co-occurrence of the eponymous genera and is devoid of the elements of Staffellinae which are very abundant in the underlying zone. Chusenella and Yangchienia in this assemblage are valuable age-indicators. C. quassiovulifera Wang and Zhou, 1986 has been reported from Murgabian strata of Lhasa Block in Tibet (Wang and Zhou, 1986) and early Midian deposits in Transcaucasus (Kotlyar, 1989). C. wuhuehensis (Chen, 1956) mainly occurs in the Maokouan strata of Tibet and South China (Chen, 1956; Xiao et al., 1986; Wang and Zhou, 1986). Yangchienia haydeni suggesting the Murgabian–Midian age in the underlying zone also persists into this zone. Thus, the Chusenella–Rugosofusulina assemblage zone is regarded also to be Murgabian–Midian in age. The age of these two zones in the Bawei Section could not be further refined, due to the absence of index fusulinids for Middle Permian biochronology, e.g. species of Neoschwagerina, Verbeekina or Yabeina.

It is conspicuous that fusulinids from the Bawei area differ from coeval fusulinids of the Xiaoinizhain area. Such a distinction is considered to result from varying sedimentary environments. Nankinella, Neofusulinella and Staffella are very abundant in the first assemblage of the Bawei Section and they all belong to Subfamily Staffellinae (Zhou and Sheng, 1994). This subfamily has been interpreted to be ecologically adapted to restricted shallow marine which is close to the costal margin of a carbonate platform, thus the structure of their spheroteca are usually severely affected by dolomitization (Ross, 1982; Zhou and Sheng, 1994). The host rocks of fusulinids in the Bawei Section are more or less dolritic as indicated by X-ray diffraction analysis and euhedral dolomites (Fig. 11) have been observed in thin sections from the levels yielding the Yangchienia–Nankinella assemblage. Therefore, fusulinids in the Bawei Section, especially those in the first assemblage, are interpreted to live in a restricted lagoon which is not suitable for the majority of fusulinid genera.

### 3.2.3. Nansan area

During a field work in 2011, we collected six new samples from three localities near the Nansan Town (Locality 17 in Fig. 1) in the southern Baoshan Block. Four samples from an outcrop near a brick factory about 1.5 km to the southeast of the Nansan Town yield the following species: Neoschwagerina globularis Wang et al., 1981, N.
sphaerica var. nana Sheng, 1963, Verbeekina americana, Staffella cirry Skinner and Wilde, 1967. One sample recovered near the Tea Hill about 2.8 km northwest to the Nansan Town yields Neo-
schwagerina globularis, N. sphaerica var. nana, Chusenella deprati (Ozawa, 1925), Sumatrina cf. annae brevis Leven, 1967. The last sample is a loose stone taken near Taozizhai Village and contains abundant specimens of Staffella cirry and S. cf. pseudosphaeroidea Dutkevitch, 1934. Representatives of these new materials are shown in Fig. 12. All samples except the last one were collected from the massive limestones of the Shazipo Formation. Most importantly, Neoschwagerina, a typical Middle Permian genus in the Tethyan region, is confirmed in our materials. Although this genus has been previously reported in the Baoshan Block (CSTY, 1984, 1990; Bureau, 1990), its presence has been queried due to the lack of definite illustrations. Both N. globularis and N. sphaerica var. nana share the following morphological attributes: relatively small size and subspherical test, the absence of secondary spiral septula even in outermost volutions, and the occasional disconnection between spiral septula and parachomata (Fig. 12(4)). All these indicate these two species are primitive in the evolutionary lineage of Neoschwagerina. N. globularis occurs in the Majula member (Murgabian) of the Luobadui Formation in Lhasa Block, Tibet (Wang et al., 1981); N. sphaerica var. nana occurs in the N. craticulifera in the Neoschwagerina zone of South China (Sheng, 1963). In addition, Verbeekina americana ranges from Murgabian to Midian as previously discussed in Section 3.2.1. Therefore, the new samples with Neoschwagerina are referable to Murgabian in age. The loose stone with abundant Staffella may be of a Murgabian to Midian age, because S. cirry has been initially reported from Tunisia in a level which is higher than Verbeekina-bearing beds and interbedded with Afghanella beds (Skinner and Wilde, 1967).

Fig. 9. Distribution of Middle Permian fusulinids in the Bawei Section of the southern Baoshan Block in western Yunnan, China. Inset figure shows the fusulinid-bearing levels in the measured Bawei Section.
3.3. Summary of fusulinid biostratigraphy

Sakmarian–Yakhtashian fusulinids are represented by the poorly diversified Eoparafusulina–Pseudofusulina assemblage in both northern and southern Baoshan Block (Figs. 13 and 15). Through late Yakhtashian to Kubergandian, inhospitable basalts and siliciclastics inhibit the presence of fusulinids in the Baoshan Block. During Murgabian to Midian, the southern Baoshan Block is with relatively complete successions of fusulinids. The Schwagerina assemblage and the Eopolydixodina assemblage characterize the Murgabian stage, while the Sumatrina assemblage and the Verbeekina assemblage characterize the Midian stage in the Xiaoxinzhai area. In the Bawei area, Murgabian–Midian fusulinids could be distinguished into the Yangchienia–Nankinella assemblage and the Chusenella–Rugosofusulina assemblage. Comparatively, fusulinids in the northern and southwestern Baoshan Block are less diverse. In the northern Baoshan Block, the Neofusulinella assemblage with possible Murgabian age occurs in the Daaozi Formation; the southwestern Baoshan Block yields the Middle Permian Eopolydixodina assemblage which is similar to that in the southern Baoshan Block.

the Early Permian ones. More significantly, the Family Verbeekini-
dae and Neoschwagerinidae became increasingly dominant
through Murgabian to Midian in the Baoshan Block. This trend is
well embodied in the Xiaoxinzhai area. Genera of these two fami-
lies, e.g. Verbeekina, Pseudodoliolina and Armenina, already
appeared during the Murgabian in the Xiaoxinzhai Section, but
they remained subordinate to elements of Family Schwagerinidae,
e.g. Chusenella, Schwagerina and Eopolydiexodina. In contrast, coeval
fusulinids in sections from tropical South China were already domi-
nated by diverse Verbeekinids and Neoschwagerinids, e.g. Neos-
chwagerina, Verbeekina, Sumatrina, Yabeina, Afghanella, Pseudodoliolina etc. (Xiao et al., 1986; Sheng and Jin, 1994). In the
Midian time, Verbeekinids and Neoschwagerinids, such as abun-
dant Verbeekina and Sumatrina took over the dominance in the
Xiaoxinzhai area. These two families compose 10 of 14 species in
the Sumatrina assemblage and 8 of 11 species in the Verbeekina
assemblage, respectively, in the Xiaoxinzhai Section.

4. Paleoclimatic and paleogeographic implications

During the Permo-Carboniferous periods, three major bioge-
ographic realms of fusulinids have been recognized regarding their
global distribution: Franklinian-Uralian realm (Boreal realm) in
the northern high latitude, Tethyan realm extending over the vast

![Fig. 11. Photomicrographs of the Nankinella-bearing limestones in the Bawei Section of the southern Baoshan Block in western Yunnan, China. Note the dolomitic feature of these limestones and the euhedral dolomites in the shell of Nankinella.](image1)

![Fig. 12. Representatives of fusulinids from Nansan area of the southern Baoshan Block in western Yunnan, China. 1 Chusenella deprati (Ozawa, 1925), Cat. No. 111226-1-b, 2 Sumatrina cf. annae brevis Leven, 1967, Cat. No. 111226-1-k, 3, 4, 7 Neoschwagerina globularis Wang et al., 1981, Cat. No. 111226-1-i, 111226-1-c, 4 is the enlargement of outermost volutions to show the absence of secondary spiral septula and occasional disconnection of septula and parachomata, 5 Staffella circy Skinner and Wilde, 1967, Cat. No. 110927-3-c, 6 5. cf. pseudosphaeroide Dutkevitch, 1934, Cat. No. 111228-2-a, 8, 9 Neoschwagerina var. nana Sheng, 1963, Cat. No. 111226-1-I, 111224-1-b, 10 Verbeekina americana, Cat. No. 111224-4-a. (All specimens housed in the Institute of Geology, Chinese Academy of Geological Sciences).](image2)
tropical and subtropical region of Tethys and Panthalassa, and Mid-continent-Andean realm (North American realm) (Ross, 1967, 1979, 1995; Bond and Wignall, 2009). Furthermore, a southern transitional zone consisting of peri-Gondwana terranes was distinguished during the Early Permian (Shi et al., 1995; Davydov and Areffard, 2007). Early Permian fusulinids in this transitional province were named as “Kalaktash Assemblage” and characterized by low diversity and dominance of fusiform Eoparafusulina and Pseudo fusulina (Leven, 1993; Davydov and Areffard, 2007). Such compositional feature radically differs from that of Early Permian fusulinids from tropical/subtropical Tethyan region (e.g. South China, North Afghanistan, Indochina and Akiyoshi Limestone of Japan), which are much more diverse (Fig. 13) and dominated by spherical, loosely-coiled Pseudoschwagerinids, e.g. Pseudoschwagerina, Robustoschwagerina, Zella and Sphaeroschwagerina (Toriyama, 1958; Sheng and Jin, 1994; Fontaine et al., 1995; Charoentitirat et al., 1997; Leven, 1997; Fontaine, 2002). These elements of Pseudoschwagerinids are absent in the Baoshan Block. Instead, Early Permian fusulinids of the Baoshan Block only yield two genera Eoparafusulina and Pseudo fusulina and the specimen abundance is rather high. Such taxonomic features demonstrate that the Baoshan Block was isolated from the Tethyan realm, and paleobiogeographically belong to the southern transitional zone (peri-Gondwana areas) during the Early Permian. Detailed comparison at the species level revealed that the Baoshan Block shared more common Early Permian fusulinid species with East-Central Iran, Central Pamir and South Afghanistan than with other peri-Gondwana areas (Shi et al., 2011).

The Early Permian fusulinids in the Baoshan Block also bears clues for the paleoclimatic condition. Most fusulinid genera are interpreted to thrive in clear, warm and shallow seas with normal salinity, based on their morphological resemblance to photosymbiotic larger benthic foraminfera in modern seas, association with green algae and hermatypic corals, as well as sedimentary facies analyses (e.g. Ozawa, 1970; Van Ginkel, 1973; Sheng et al., 1988; Ross, 1995; Della Porta et al., 2005; Davydov and Areffard, 2007; Stevens and Stone, 2007; BouDagher-Fadel, 2008; Vachard et al., 2010; Groves et al., 2012; Davydov et al., 2013). The inflated Pseudoschwagerinids, especially Robustoschwagerina and Zella, are mostly confined in the warm-water tropical/subtropical region and associated with diverse other fusulinid genera (Ross, 1995; Vachard et al., 2010). Accordingly, the poorly diversified Eoparafusulina assemblages without or with sporadic such Pseudoschwagerinids in the peri-Gondwana region have been explained to indicate the southern temperate zone with a paleolatitude higher than 30°S and an annual sea-surface temperature range around 14–20 °C (Leven, 1993; Davydov and Areffard, 2007).

Nevertheless, sea-surface temperature is not the sole cause resulting in such taxonomic composition of these Eoparafusulina assemblages. Similar poorly diversified Eoparafusulina assemblages without inflated Pseudoschwagerinids also could be found in the equatorial South China (Sheng and Jin, 1994), which maintained its position near the equator during the Permian (Nie, 1991). These occurrences in South China are restricted in nearshore sand shoals (Zhang et al., 1988), thus is controlled by the sedimentary facies rather than water temperature. Therefore, Shi et al. (2011) inferred that the Eoparafusulina assemblages of the Baoshan Block suggested either temperate water or nearshore environment. Besides, Leven and Gorgij later in 2011 changed their viewpoint and argued that the Kalaktash assemblage from Central Pamir and Central Iran inhabited in low latitude with warm water, mainly because oolitic limestones occur slightly below the Eoparafusulina assemblage in these areas (Leven, 1993; Leven and Gorgij, 2011). Meanwhile, Leven and Gorgij (2011) insisted that the Kalaktash assemblages from South Afghanistan and Karakorum still denote cool environment, as these assemblages rest immediately on beds with bryozoans and bivalves typical of cool-water Gondwana affinity. Similarly, brachiopods (Stenocisma and Elivina) and corals (small solitary Lytvolasma and Cyathaxonia) from the fusulinid-bearing limestones and underlying siliciclastics of the Dingjiazhai Formation show cool-water Gondwana affinity (Fang, 1994; Fang and Fan, 1994; Shi et al., 1996; Wang et al., 2001). Moreover, Yan and Liang (2005) stated that the limestones in the top of the Dingjiazhai Formation belong to the bryonoderm-extended facies of the cool-water heterozoan association, although fusulinids are not shown in their samples. Our observation (Fig. 14, left) further confirmed that the host rocks of the Eoparafusulina assemblage are fitted grainstone, lacking early cementation and non-skeletal grains (e.g. peloids and ooids), thus also belong to the temperate-water heterozoan association (James, 1997; Flügel, 2010). Based on these combined evidence, we conclude that the Early Permian fusulinids of the Baoshan Block lived in temperate water condition. Although the appearance of these fusulinids signifies the onset of climatic amelioration after the deposition of glaciogenic diamictites and cool-water fossils, the paleolatitude of the Baoshan Block is envisaged to be distant from the tropical region during Sakmarian–Yakhtashian and even with higher latitude than Central Iran and Central Pamir where oolites and Pseudoschwagerinids already occurred. This is compatible with the paleomagnetic data which show that the Baoshan Block was located at 41.9°S (with errors,
34.2–51.2°S) during the eruption of the Woniusi basalts immediately overlying the *Eoparafusulina*-bearing levels (Ali, 2013).

According to the qualitative comparison by Ozawa (1987) and Kobayashi (1997a, 1997b), the Middle Permian Tethyan realm could be further divided into Western Tethyan Province and Eastern Tethyan–Panthalassan Province. This subdivision was recently confirmed by quantitative analysis of global distribution of Permian fusulinids by Bond and Wignall (2009). The eastern Tethys is rich in diverse Verbeekinids and Neoschwagerinids and contains certain endemic genera such as *Lepidolina* and *Metadoliolina*, mainly covering the North and South China, and the major part of Indochina (Ozawa, 1987; Bond and Wignall, 2009). The western Tethys contains relatively less diversified fusulinids and is distinguished by endemic *Eopolydixodina* and *Sasioella* as well as common association of *Rugososchwagerina* and *Chusenella* (Ozawa, 1987). Geographically, the western Tethyan province covers Afghanistan, Greece, Iran, Northern Hungary, Oman, Pakistan, Southern Italy, Transcaucasia, Tunisia and Turkey (Bond and Wignall, 2009). However, the paleobiogeographic affinity of the Baoshan Block was not explicitly determined by these authors, due to the inadequacy of fossil materials.

Updated from the recent studies by Ueno (2003) and Huang et al. (2009), the data in present paper allow us to ascertain the paleobiogeographic affinity of the Middle Permian fusulinids in the Baoshan Block. First of all, Family Verbeekinidae and Neoschwagerinidae have been acknowledged to be thermally stenotopic and typify the warm-water environment in the tropical/subtropical Tethyan region (Gobbett, 1967; Ross, 1982; Stevens, 1985; Ozawa, 1970; Ueno, 2003). The presence of these two families, therefore, indicates that the Baoshan Block already yielded Tethyan elements during the Middle Permian. Furthermore, *Eopolydixodina* is very abundant among the Middle Permian fusulinids of this block and this genus is endemic in the western Tethys (Ozawa, 1987; Vachard and Bouyx, 2002; Ueno, 2003). Besides, the Yangchienia and Chusenella in association are also common in the western Tethyan region during the Middle Permian (Ozawa, 1987; Ueno, 2003); Xiaoxinzhaiella is hitherto confined in western Tethyan localities, e.g. Lhasa Block of Tibet, Baoshan Block, Central Iran and South Afghanistan (Shi et al., 2005; Huang et al., in press). Therefore, the Middle Permian fusulinids of the Baoshan Block, as a whole, belong to the western Tethyan province in the Tethyan realm. Moreover, a delicate change in the paleobiogeographic affinity of Middle Permian fusulinids in the Baoshan Block could be further discerned. The dominant taxa changed from Schwagerinids to Verbeekinids and Neoschwagerinids in the Murgabian to Verbeekinids and Neoschwagerinids in the Midian fusulinids of the Baoshan Block (Fig. 15). Meanwhile, *Eopolydixodina* becomes rare in the *Sumatrina* zone and fails to persist into the youngest Verbeekina assemblage in the Xiaoxinzhai area. These reveal that, compared with the Murgabian ones, the Midian fusulinids in the Baoshan Block show closer affinity with the eastern Tethyan province.

The shallow-marine temperature of the Baoshan Block during the Middle Permian was considerably ameliorated, judging from the much higher diversity of the Middle Permian fusulinids. Moreover, the predominance of the typically warm-water Verbeekinids and Neoschwagerinids in the Midian fusulinids of the Baoshan Block reveals that the water condition was probably even warmer in the Midian than in the Murgabian. Such climatic amelioration from Early to Middle Permian is also supported by the change in corals from *Cyathaxonia* to *Wentzelophyllum* fauna (Wang et al., 2001), and the shift from heterozoan to photozoan association in carbonate facies (Yang and Liang, 2005) in the Baoshan Block. Of particular interest is that ooids, which characterize warm seawater (James, 1997; Rankey and Reeder, 2009; Flügel, 2010), was reported, but with no figure proof, from the Middle Permian Yongge Formation and Shazipo Formation in the Baoshan Block (Yang and Liang, 2005). In our measured Xiaoxinzhai Section, ooids have been confirmed to be present in the Shazipo Formation and even abundant to form ooid grainstone immediately below the Midian *Sumatrina* assemblage (Fig. 14, right).

On the other hand, the Murgabian–Midian water temperature of the Baoshan Block probably was still not as optimal as that of equatorial region for the diversification of fusulinids. The total generic diversity of the Murgabian–Midian fusulinids in the Baoshan remained much lower than that of the typically tropical region, e.g. South China and East Thailand of Indochina (Fig. 13). Consistently, Ueno (2003) suggested that, among all Gondwana-derived blocks, the Baoshan Block and the Sibumasu Block (Shan State of Burma, western and Peninsular Thailand, western Peninsular Malaysia, northeast Sumatra) had the lowest diversity of the Middle Permian fusulinids and probably were located in relatively high latitude with temperate water. According to the ecological requirement of fusulinids summarized above, the diversity of fusulinids is mainly controlled by sea-surface temperature, siliciclastic input and salinity. When fusulinids from vast regions (e.g. continental blocks) over a long time interval (e.g. epoch) are compared, the effects of siliciclastic detriment and salinity oscillation would be at least minimized, if not completely eliminated. That is fusulinids from a vast area during long interval usually incorporate assemblages from shallow marine environments of varying siliciclastic content and salinity, both of which are relatively local sedimentary factors. Even in a single section of deposits within short duration (~0.6–1.2 myr), water temperature has been proved to overpower the sedimentary factors in controlling the fusulinids diversity (Khodjanyazova et al., 2014). Therefore, we argue that latitudinal gradient of water temperature is the most likely reason for the discrepancy in fusulinid diversity between tropical region and Baoshan Block or Sibumasu Block.

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Meanwhile, it should be emphasized that the data on Middle Permian fusulinids of this paper essentially differentiate the Baoshan Block from the majority of the Sibumasu areas (Fig. 14). Previously, the Baoshan Block has been regarded paleogeographically a part of the Sibumasu Block (Metcalfe, 2002), and together with the Sibumasu Block constitutes the eastern Cimmerian subprovince in terms of fusulinid paleobiogeography (Ueno, 2003). Our data show that Verbeekinids and Neoschwagerinids indicative of warm-water are prosperous in the Baoshan Block during the Middle Permian. In marked contrast, elements of these two families have, heretofore, generally not been found in the Sibumasu Block (Fontaine and Gafoer, 1989; Fontaine et al., 1994; Ueno and Hisada, 2001). The Sibumasu Block was thus interpreted to still lie in peri-Gondwana region with relatively high latitude and temperate to cool water (Ueno, 2003). The only reliable exception is that Ingavat-Helmcke (1993) illustrated the occurrence of Pseudodoliolina near Don Sak in Peninsular Thailand. In addition, Latt and Ueno (2008) reported Neoschwagerina, Sumatrina, Verbeekina, Pseudodoliolina and others from the western margin of Shan State of Burma, but gave neither firm illustration nor description. Even though, the Baoshan Block still remarkably differs from the majority of Sibumasu areas by yielding relatively more diverse Verbeekinids and Neoschwagerinids. Therefore, the Baoshan Block was very likely located at lower latitude to the north of western and Peninsular Thailand, western Peninsular Malaysia, northeast Sumatra during the Murgabian–Midian.

Furthermore, the Midian Verbeekina assemblage recently found in the Xiaoxinzhai Section provides corroborative evidence for paleoclimatic interpretation. This assemblage is with relatively low total diversity and overwhelming abundance of only one genus, i.e. Verbeekina (Huang et al., in press). Such feature is not common for Verbeekina assemblage, which usually comprises the highly diversified association of Verbeekina, Neoschwagerina, and Pseudodoliolina etc. Low diversity and rather abundance of very few taxa generally reflect somewhat stressful environment for larger benthic foraminifera (Belasky, 1996; Dixon and Haig, 2004; Jones, 2014). Detailed facies analysis has excluded the possibilities of severe siliciclastic detriment or abnormal salinity due to restricted water circulation (Huang et al., in press). Consequently, the Verbeekina assemblage of the Xiaoxinzhai Section indicates that, even in the Midian time, the sea-surface temperature of the Baoshan Block was still not ideal for the diversification of the fusulinids. In sum, the Murgabian–Midian fusulinids of the Baoshan Block reveal that this Block hosted warm, but still not optimum sea water for fusulinids during that time and its paleogeographic position probably was located at subtropical region or marginal area of tropical region, with equatorial South China and Indochina to the north and the Sibumasu areas lacking Verbeekinids and Neoschwagerinids to the south.

It is also noteworthy that the Middle Permian Baoshan Block has been regarded to belong to a transition zone named Cimmerian Province between Gondwana realm to the south and Eastern Tethyan realm. }
yan province to the north (Ueno, 2003; Zhang et al., 2013). This transitional province is characterized by the mixture of fossils from both warm-water Eastern Tethyan and cool-water Gondwana region, moderate fossil diversity and some endemic anti-tropical genera (Shi et al., 1995; Grunt et al., 1997; Shi and Archbold, 1998). Judging from the characteristic fossil association, the Cimmerian province may be correlated to the southern areas of the western Tethys of Ozawa (1987) (e.g. Afghanistan and Karakorum), where marine fossils are more influenced by the cool-water from Gondwana realm, thus bears more Gondwana affinity than the northern areas in the western Tethys (e.g. Tunisia, Carnic Alps, Transcaucacus and Sicily). It is more difficult to recognize this transitional zone based on fusulinids than on brachiopods, because no fusulinid genera are typically Gondwana type. However, we realized that the moderate diversity of Middle Permian fusulinids in the Baoshan Block show a signature of the transitional zone. In addition, Shi and Shen (2001) reported a mixed brachiopod fauna with both Cathaysian and Gondwanan affinities from the basal Shazipo Formation. If both the data of brachiopods and fusulinids are taken into account, the Baoshan Block may be considered part of the Cimmerian province at least for the Murgabian time.

5. Conclusions

The following conclusions have been achieved by analyzing the published data and our newly obtained materials of Permian fusulinids in the Baoshan Block:

1. Biostratigraphically, Sakmarian–Yakhtashian fusulinids are represented by the Eoparafusulina–Pseudofusulina assemblage in both northern and southern Baoshan Block. Murgabian–Midian fusulinids are more prosperous in the southern Baoshan Block and could be grouped into, in ascending order, the Schwergerina assemblage, the Eopolydixodina assemblage, the Sumatrina assemblage and the Verbeekina assemblage in the Xaoxinhzhai area, and the Yangchienia–Nankinella assemblage and the Chusenella–Bugosofusulina assemblage in the Bawei area. Meanwhile, the Middle Permian fusulinids are represented by the Neofusulinella assemblage in the northern and the Eopolydixodina assemblage in the southwestern Baoshan Block, respectively.

2. The Sakmarian–Yakhtashian fusulinids suggest a temperate–water condition, as they are poorly diversified and associated with cool-water fossils and carbonate facies. Sea-surface temperature increasingly ameliorated through the Murgabian to Midian. This warming trend is evidenced by the much higher diversity of the Middle Permian fusulinids and the fact that Verbeekinids and Neoschwagerinids, diagnostic for warm water, changed from subordinate to dominant. However, even the Midian water temperature of this block was very likely not as ideal for the diversification of fusulinids as that of the equatorial region.

3. The Sakmarian–Yakhtashian fusulinids can be well correlated to the so-called Kalaktash assemblage confined in Gondwana-derived blocks, and thus belong to the peri-Gondwana province. The paleobiogeographic affinity of the Murgabian–Midian fusulinids is western Tethyan, on the basis of the moderate diversity and the association of Eopolydixodina, Xiaoxinhzhaiella, Chusenella and elements of Verbeekinids and Neoschwagerinids.

4. Paleogeographically, the Baoshan Block probably was situated distant from the tropical region, and even with higher latitude than Central Iran and Central Pamir during the Sakmarian–Yakhtashian. During the Murgabian–Midian, this block is interpreted to be located between the tropical South China and Indochina to the north and the majority of Sibumasu areas (i.e. western and Peninsular Thailand, western Peninsular Malaysia, and northeast Sumatra) to the south, and at subtropical or marginal tropical region.

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