

# Permian stratigraphy and correlation of Northeast China: A review

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## Abstract

Palaeontological, lithostratigraphical data from the Permian strata and correlation of the Permian successions for different tectonic units in Northeast China are reviewed and summarized in this paper. Permian strata in Northeast China are dominated by brachiopods, fusulinoideans and land plants, with limited ammonoids, conodonts and bivalves. The Cisuralian (Early Permian) in the northern margin of the North China Block and in the Manchuride Belt is composed mostly of marine massive limestone with the characteristic *Pseudoschwagerina* Zone in the Asselian and Sakmarian and the *Misellina claudiae* Zone in the Kungurian. The Cisuralian in the Xing'an Block and the northeastern part of Inner Mongolia is dominated by huge terrestrial deposits with fossil plants. The Guadalupian (Middle Permian) in the Manchuride, Altaid and Yanbian Belts are characterized by bi-temperate Roadian or early Wordian *Monodioxodina* fauna and the late Wordian–Capitanian *Codonofusiella*–*Schwagerina* or *Neoschwagerina*–*Yabeina* faunas, the mixed brachiopod faunas between the Boreal/antitropical and the Palaeoequatorial Cathaysian forms, the Roadian or early Wordian solitary coral faunas, and the late Wordian–Capitanian compound *Waagenophyllum*–*Wentzelella* fauna. The Nadanhada Terrane contains some exotic limestone blocks with a typical Cathaysian *Neoschwagerina*–*Yabeina* fauna in a Late Jurassic–Early Cretaceous mélange, which is related to Mesozoic subduction in the western Circum-Pacific region. The Lopingian (Late Permian) in Northeast China is mostly characterized by terrestrial molasse deposits with a mixed flora between the Boreal Angaran and the palaeoequatorial Cathaysian Provinces, indicating the final closure of the Palaeo-Asian Ocean.

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## 1. Introduction

Northeast China is the eastern segment of the Xingmeng (Xing'an Ranges and Mongolia) Orogenic Belt, which forms the east part of the Central Asian Orogenic Belt (CAOB) or the Altaid Tectonic Collage (Sengör et al., 1993). Since this area is within a broad collisional zone, the stratigraphy and tectonic evolution are extremely complicated (Tang, 1989; 1990; Guo et al., 1992; Parfenov et al., 1993; Ye et al., 1994; Shao et al., 1995a; Chen et al., 2000; Badarch et al., 2001). Bordering the complex collisional zone to the south is the North China Block and to the north is the Siberian Block. In the southeast part of CAOB, Sengör and Natal'in (1996) separated the Manchuride Orogenic Belt which lies immediately to the north of the North China Block, from the rest of the Altaid accreted terranes. The suture between

the Manchuride Orogenic Belt and the Altaid Orogenic Belt is represented by the Solonker zone, which extends from Solonker to Sonidzuoqi and Xilinhot in northern Inner Mongolia. This terrane suture has been generally considered as the suture between the North China Block and the Siberian Block (e.g. Jia et al., 2004). In the east, there are five microcontinental blocks/terranes and the Yanbian Fold Belt. They are the Xing'an Block in the north, the Songliao-Zhangguangcai Block in the southwest, the Nadanhada Terrane in the southeast, the Jiamusi Block in the middle, and the Khanka (Xingkai) Block in the south (Cao et al., 1992; Ye et al., 1994; Wu et al., 2000; Jia et al., 2004) (Fig. 1).

Permian strata and deposits in Northeast China record the closure of the Palaeo-Asian Ocean and the collision and ultimate consolidation between the Siberian and the North China Blocks (Li et al., 1982a; Wang, 1986; Wang and Liu, 1986), and therefore have received considerable attention from geologists during the last century (Li and Gu, 1984; Wang and

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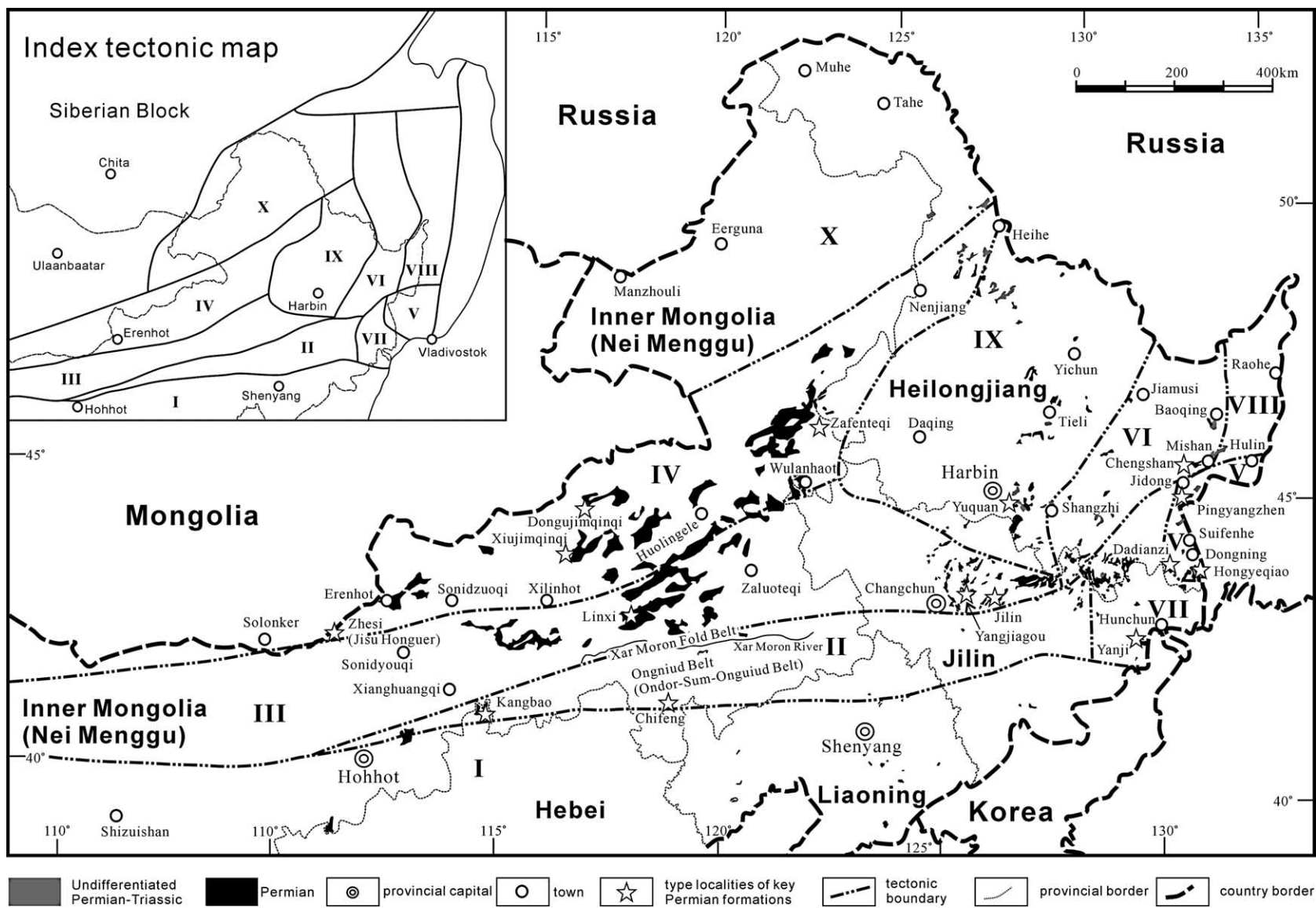


Fig. 1. Tectonic subdivision and distribution of Permian strata in Northeast China (Data after Editorial Committee of Geological Atlas of China (ECGAC), 2002). I, North China Block; II, Northern margin of North China Block; III, Manchuride Belt; IV, Altaid Belt; V, Khanka Block; VI, Jiamusi Block; VII, Yanbian Fold Belt; VIII, Nadhanda Terrane; IX, Songliao-Zhangguangcai Block; X, Xing'an Block.

Liu, 1986; Shi et al., 1995). However, previous stratigraphical studies were relatively sporadic and there has been little attempt to synthesize the Permian lithostratigraphy and biostratigraphy, except for the brief summary provided in a general review of Permian stratigraphy all over China by Sheng and Jin (1994), and an account of Permian stratigraphy in the eastern Inner Mongolian area by Guo et al. (1991). This paper aims to provide a general review of the Permian lithostratigraphy, biostratigraphy and correlation based on different faunal groups, and to discuss the palaeobiogeographical division and tectonic evolution of the different tectonic units in Northeast China.

## 2. Lithostratigraphy and biostratigraphy

Permian strata are widely distributed in Northeast China (Fig. 1), but most have been tectonically disturbed. They are characterized by marine deposits in the Lower and Middle Permian, and continental deposits in the Late Permian (Li and Gu, 1984; Guo, 1995; Krasnyi et al., 1996; Su, 1996a; Wang and Su, 1996).

Permian biostratigraphy in Northeast China, discussed below, is based mainly on fusulinoideans, brachiopods, land plants, ammonoids and conodonts, which are inadequate for the purpose of high-resolution biostratigraphy in terms of detailed Tethyan successions (e.g. Mei et al., 1994; 1998; Mei and Henderson, 2002; Henderson and Mei, 2003). In addition, there are great discrepancies in the correlation between Kungurian, Roadian and Wordian Stages according to the Tethyan and the North American scales (Lambert et al., 2000; Wardlaw, 2000; Leven, 2001; 2004; Mei and Henderson, 2002; Henderson and Mei, 2003). In this paper, we follow the Permian time scale of Jin et al. (1997, 1999) although very limited conodont data are available in Northeast China, and associated fusulinoideans cannot resolve the discrepancies between North America and the Tethys because of profound provincialism (Henderson and Mei, 2003). In this account, the Permian deposits of Northeast China are discussed in terms of the tectonic units (I–X) in which they occur shown in Fig. 1.

### 2.1. Northern margin of the North China Block (II)

The oldest ophiolite along the northern margin of the North China Block (I) is the Onder Sum ophiolite occurring in the Xar Moron Fold Belt (Tang, 1990), which is considered to be the division between the North China Block (I) and the Manchuride Orogenic Belt (III) (Tang, 1990). The Permian marine deposits are developed in a narrow E–W zone, the Ongniud Belt of Guo et al. (1991) or the Ondor Sum–Ongniud Belt of Wang and Liu (1986) along the northern continental margin of the North China Block (Fig. 1). In the east, this zone is directly faulted with the Yanbian Fold Belt near the border between China and the Korean Peninsula. The Cisuralian is mostly missing in this region. The earliest Permian unit is called as the Sanmianjing Formation (Fig. 2A). Its type locality is at Kangbao near the border between Hebei Province and Inner Mongolia. The

Sanmianjing Formation overlies Variscan gneissose quartz diorite unconformably. The lowest part of the formation is about 55 m thick and consists of yellowish sandy conglomerate, which is followed by thick-bedded limestone, cherty limestone and sandy limestone of 30 m thick containing abundant fusulinoideans including *Misellina claudiae*, *M. ovalis*, *M. minor*, *Minojapanella* (*Wutuella*) sp., *Parafusulina splendens*, *P. bosei* and *Chusenella* aff. *schwagerinaeformis* and the brachiopods *Orthotichia morganiana*, *O.* aff. *derbyi*, *Marginifera* sp. (Li, 1986; Su, 1996a; BGMRNM (Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region), 1991, 1996). The fusulinoidean fauna in the lower 30 m of the Sanmianjing Formation is correlative with the *Misellina ovalis*–*Parafusulina splendens* Zone of Xia (1981), the well-recognized *M. claudiae* Zone or the *Armenia*–*Misellina ovalis* Zone of Leven (2004) and indicates a Kungurian age in terms of the three-fold Permian timescale (Jin et al., 1997) or Kubergandian of Leven (2004).

The upper part of the Sanmianjing Formation is about 200 m thick and is dominated by grayish green siltstone, fine-grained sandstone, silty slate and shale, occasionally with plant fragments, but no marine fossils (Fig. 2A). The Sanmianjing Formation is overlain unconformably by andesite of the Jurassic Manitu Formation at the type locality.

Slightly north of the type locality of the Sanmianjing Formation, the Elitu Formation is considered to be largely equivalent to the Sanmianjing Formation (Li and Gu, 1976; Gu et al., 1983; Huang, 1986; BGMRNM, 1991, 1996; Li in Jin et al., 2000). The Elitu Formation is more than 1667 m thick and dominated by fine- to coarse-grained sandstone, shale and tuff. In the interbedded shale, the fossil plants such as *Pecopteris tenuicostata*, *Sphenopteris grabau*, *Odontopteris chui*, *Danaeites mirabilis*, *Gigantonoclea borenli*, *Taeniopteris norinii*, *Annularia gracilescens*, *Asterophyllites slituensis* have been reported (Huang, 1986; 1993; BGMRNM, 1991, 1996; Li in Jin et al., 2000). Occasionally, the Elitu Formation contains some marine units, but only ‘*Canocrinella*’, a brachiopod with a very long range, has been recorded (BGMRNM, 1996; Li in Jin et al., 2000).

In the Chifeng area, southeastern Inner Mongolia (Fig. 1), the earliest Permian lithological unit is named the Jiujuzi Formation (Fig. 2B), which overlies conformably the Upper Carboniferous Baijiadian or Shizuizi Formation (BGMRNM, 1991, 1996). The Jiujuzi Formation is characterized by terrestrial or terrestrial–marine deposits and is composed mainly of purple thin-bedded slate and fine-medium sandstone containing rare fossil plants (BGMRNM, 1991, 1996). The fossil plants include *Calamites* sp., *Neuropteris pseudovata*, *Pecopteris?* sp. and *Callipteridium* sp., which probably suggest a Cisuralian age (Huang, 1993; BGMRNM, 1996).

The Jiujuzi Formation is overlain by the Qingfengshan Formation, which consists mainly of grayish green slate, and intermediate tuff intercalated with basalt (Fig. 2B). Fossils are very rare and only crinoid fragments were found in the basal conglomerate unit of this formation, implying that the formation is marine (Huang, 1993). The Qingfengshan Formation is considered to be largely equivalent to the Elitu/

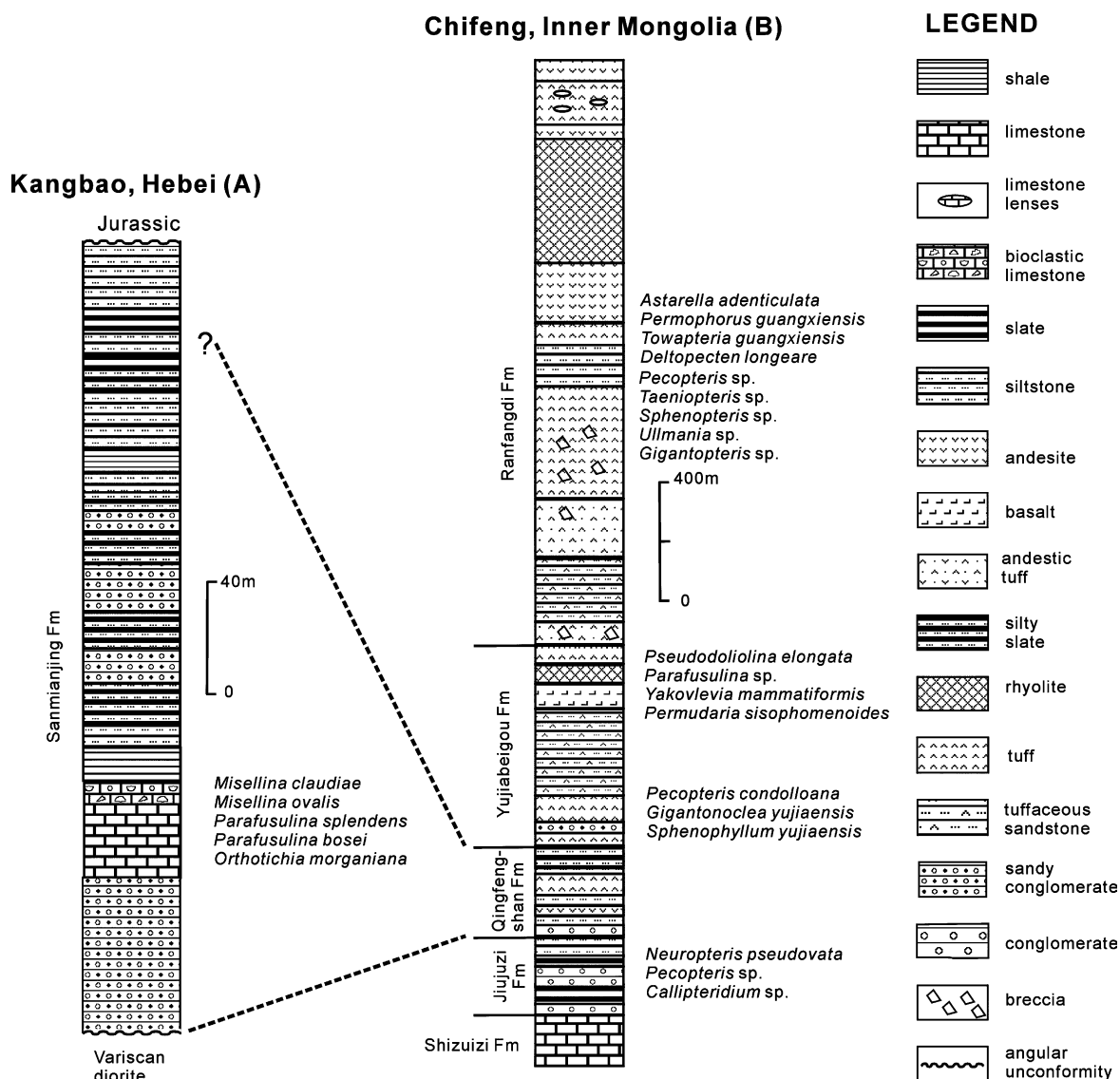


Fig. 2. Permian stratigraphical columns from the northern margin of North China Block (II) (data after Gu et al., 1983; Li, 1986; Li in Jin et al., 2000; Li and Gu, 1976; Huang, 1986; 1993; BGMNM, 1991; 1996; Su, 1996a).

Sanmianjing Formation in the Kangbao area in terms of the similar lithology (Huang, 1986; 1993).

The Qingfengshan Formation is conformably followed by the Yujiabeigou Formation (Fig. 2B), which is 674 m thick (Gu et al., 1983; Huang, 1993). The lower 450 m of this formation is mainly composed of acidic tuff, massive andesite and tuffaceous sandstone containing a few fossil plants including *Pecopteris condolloana*, *Gigantonoclea yujaensis*, *Annularia gracilescens*, *Taeniopteris integra* and *Sphenophyllum yujaensis* (Gu et al., 1983). In pale green fine-grained tuffaceous siltstone in the upper part of the formation, abundant marine and fossil plants were reported (Huang, 1993). The marine fossils include the fusulinoideans *Pseudodoliolina elongata*, *Parafusulina* sp.; the brachiopods *Yakovlevia mammatiformis*, *Y. kalaziensis*, *Permudaria sisophomenoides*, *Spiriferellina* cf. *cristata*, *Leptodus* sp. and *Lissochonetes* sp.; and the fossil plants *Sphenophyllum*

*yujaensis*, *Annularia gracilescens*, *Pecopteris candoleata*, *Tingia carbonica*, *Gigantonoclea microphylla*, etc. (Li et al., 1980; Huang, 1993). The fusulinoideans *Pseudodoliolina* and *Parafusulina* are commonly associated with *Monodiexodina* in Northeast China, and have been regarded as the commonest elements of the late Chihsiian or early Maokouan in South China (Han, 1980; Ding et al., 1985; Jin et al., 1999; Leven, 2004) or early Maokouan in the Yanbian area of Jilin Province (Sun, 1990; Ueno and Tazawa, 2003). The age suggested by the fusulinoideans is also compatible with the associated brachiopods. *Permudaria* has been commonly recorded from the Maokouan in South China (Jin et al., 1974) and Cambodia, and the lower Kanokura Formation (Wordian) in South Kitakami, northeast Japan (Nakamura et al., 1970). *Yakovlevia mammatiformis* and *Y. kalaziensis* are very common in the lower part of the Jisu Honguer (Zhesi) Formation in the Zhesi area, Inner Mongolia. The

lower part of the Jisu Honguer Formation is considered to be early Maokouan (early Wordian) (Ding et al., 1985) and Ufimian by Leven et al. (2001). The topmost part of the Yujiabeigou Formation is composed of greenish amygdaloidal basalt and andesitic tuff (Fig. 2B).

The Upper Permian deposits in the Chifeng area, Inner Mongolia are represented by the Ranfangdi Formation, which is composed of tuffaceous conglomerate, andesite and rhyolite, more than 2000 m thick (Fig. 2B). Therefore, the Ranfangdi Formation indicates very strong intermediate/acidic volcanism in the Late Permian (Huang, 1993). In the middle part of the formation, the marine bivalves *Astartella adenticulata*, *Permophorus? guangxiensis*, *Towapteria guangxiensis*, *Deltopecten longeare* and *Cyrtorostra fisuensis* and the fossil plants *Ullmania*, *Gigantopteris*, *Walchia* and *Sphenopteris* were reported (BGMRNM, 1991; Zheng, 1993).

## 2.2. Manchuride Belt in Northeast China (III)

### 2.2.1. Central Jilin area (III)

Permian strata are well developed near Jilin City in Jilin Province (Fig. 1). The Shizuizi Formation is about 1096 m thick at Shizuizi, the type locality of this formation and dominated by pale grey marble and schist, topped with fine-grained tuffaceous sandstone. This formation contains two fusulinoidean zones, the *Triticites* Zone in the lower and the *Pseudoschwagerina* Zone in the upper part. It also contains the brachiopod *Dictyoclostus* Assemblage, and some corals such as *Ivanovia*, *Carruthersella*, *Amandophyllum* and *Caninia* (Guo et al., 1992). At a locality 20 km south of Shuangyang County, abundant fusulinoideans including *Triticites schwageriniformis*, *T. mogutovensis* and *T. flaxus* in the lower, and *Rugosofusulina* cf. *vacuta*, *Pseudoschwagerina borealis*, *P. uddeni* and *Schwagerina anderssoni* in the upper part, have been reported (Tao et al., 1975). The Shizuizi Formation therefore, ranges from latest Carboniferous to Early Permian (Asselian or Sakmarian).

The Shoushangou Formation is composed mainly of thick-bedded limestone with cherty nodules in the lower and phyllitic siltstone in the upper part (Fig. 3A). The fusulinoideans *Parafusulina gruperiensis*, *P. cf. splendens* and *Schwagerina linearis*, the corals *Yatsengia* sp., *Polythecalis* sp. and *Chusenophyllum asteroidean*, and the brachiopods *Echinoconchus* sp., *Cleiothyridina* sp. and *Compressoproductus* sp. have been recorded (Tao et al., 1975). These fusulinoideans and corals are the commonest elements in the Chihhsia Formation (Han, 1980; Ding et al., 1985); therefore, the Shoushangou Formation is largely equivalent to the Chihhsia Formation of South China.

In the central Jilin area, the contact between the Shoushangou Formation and the underlying Shizuizi Formation is mostly covered by Quaternary deposits. However, Yin (1995) reported an ammonoid–brachiopod fauna from the lower part of the Shoushangou Formation, probably in conformable contact with the underlying Shizuizi Formation, containing the *Pseudoschwagerina* Zone in Panshi County in the central Jilin area. This fauna includes the ammonoids *Agathiceras*, *Bactrites*, *Paraceltites*, *Parastacheoceras* and *Artinskia*, and the brachiopods

*Waagenoconcha* sp., *Linoproductus neimongolensis*, *Neochonetes wusihibensis*, *Neochonetes brama*, and *Attenuatella paraincurvata*. The coeval fusulinoidean zone to the above ammonoid–brachiopod fauna is the *Misellina claudiae* Zone, therefore, the lower part of the Shoushangou Formation is also of Chihhsian age (Yin, 1995).

The overlying Daheshen Formation is extremely thick (3689 m) and the lower 3000 m consists of andesite, rhyolite and andesitic tuff with no fossils (Fig. 3A). The upper 700 m of this formation is mainly tuffaceous siltstone and tuff, topped with thick massive limestone. The fusulinoideans *Monodiexodina* sp., *Parafusulina* sp. and *Schwagerina* sp., the solitary corals *Tachylasma* sp. and *Lytovlasma* sp., some bryozoans, and the fossil plants *Neuropteris daheshenensis*, *Noeggerathiopsis latifolia*, *Pecopteris* sp. and *Paracalamites* sp., are recorded (Guo et al., 1992). According to Guo et al. (1992), a rich solitary coral assemblage consisting of *Szechuanophyllum szechuanense*, *Yatsengia*, *Polythecalis*, *Lophophyllum*, *Cyathocarina*, *Verbeekiella*, *Plerophyllum*, etc. was reported from the Daheshen Formation by the seventh geological team of central Jilin Province (unpublished data). This solitary coral assemblage is unique in being composed of solitary elements and there is no substantial difference from corals in the underlying Shoushangou Formation. The Daheshen Formation is probably Roadian or early Wordian in age.

The Daheshen Formation is overlain by the Fanjiatun Formation, which is composed mainly of dark siltstone, tuffaceous sandstone interbedded with a few limestone units (Fig. 3A). The fusulinoideans *Neoschwagerina craticulifera*, *Neoschwagerina simplex*, *Yabeina* sp., *Chusenella conicocylindrica*, *Lantschichites* sp., etc. the coral *Waagenophyllum* sp. and the brachiopods *Waagenoconcha* sp., *Stenosisma purdoni*, *Spiriferella* sp., etc. are recorded (Guo et al., 1992). Therefore the Fanjiatun fauna strongly suggests a Wordian to early Capitanian age in terms of the time scale of Jin et al. (1997) and Leven (2001, 2004). This correlation is compatible with the occurrence of an ammonoid fauna consisting of *Propinacoceras affine*, *Daubichites* cf. *orientalis*, *Roadoceras roadense*, *Waagenoceras* sp., *Metalegoceras* sp., *Andrianites elegans*, etc. (Liang, 1981) (Fig. 3A).

The age determination of the Fanjiatun Formation is largely compatible, with a conodont fauna consisting of seven *Jinogondolella/Mesogondolella* species (Wang, 2000). Most of conodont elements are small and have serrated platform with discrete carina. According to Wang (2000), *Mesogondolella multiserrata* is more advanced than the Roadian *Mesogondolella nanjingensis* (= *Jinogondolella nankingensis*) in terms of spaced denticles and large terminal cusp and *M. sp. B* is more advanced than the Kungurian *Mesogondolella idahoensis*, therefore suggesting a younger age than the *M. idahoensis* Zone. On the contrary, *Mesogondolella pseudoaltudaensis* is more primitive than *Mesogondolella altudaensis*. Therefore, the conodont fauna is of Wordian and early Capitanian in age (Wang, 2000). However, Mei and Henderson (2002); Henderson and Mei (2003, Fig. 4) considered that this fauna is probably Roadian or early Wordian in view of the serration

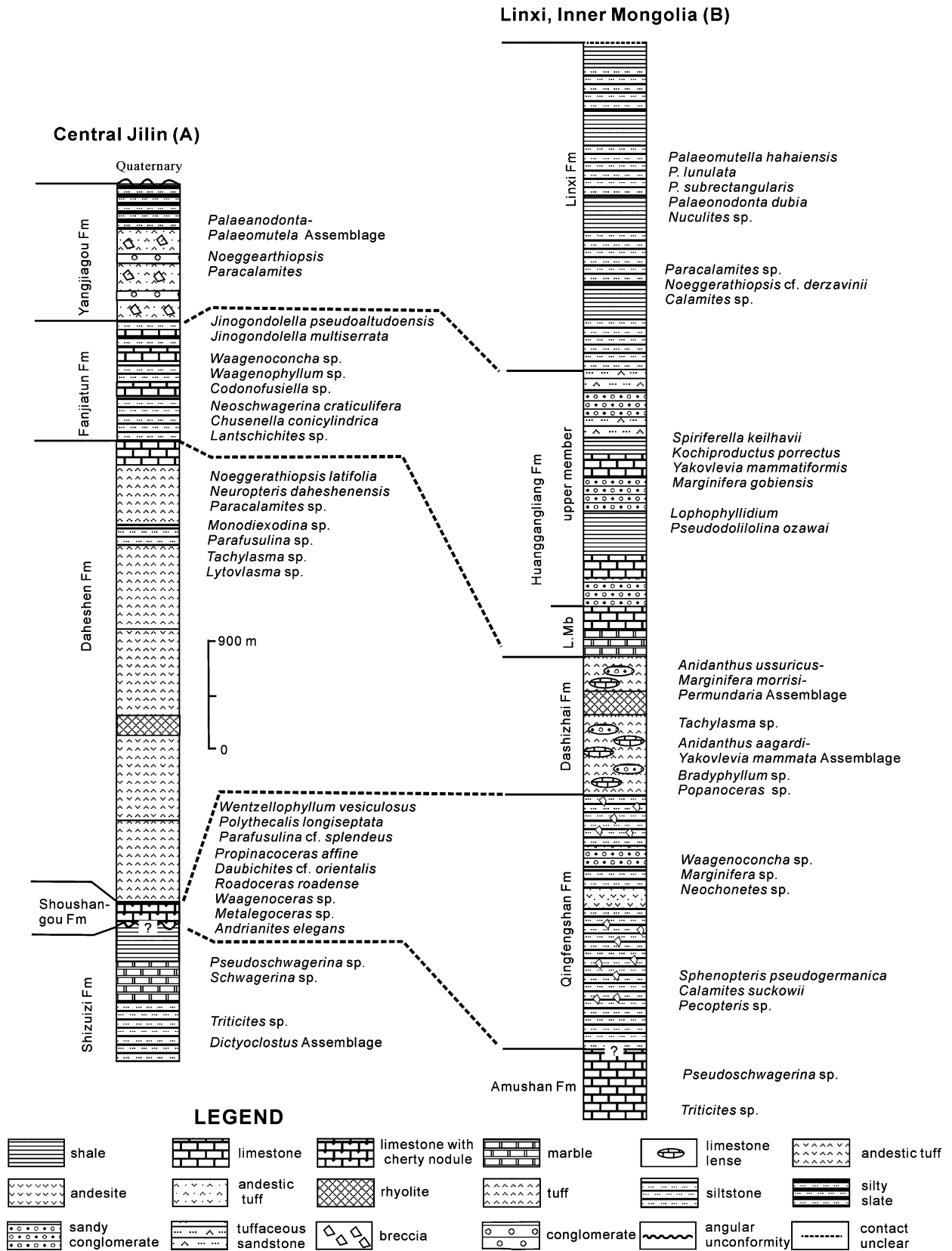


Fig. 3. Permian stratigraphical columns from the Manchuride Belt (III) (data after Tao et al., 1975; EGSCPL, 1978; Liang, 1981; Guo et al., 1992; Huang, 1993; Yin, 1995; BGMRNM, 1996; Li in Jin et al., 2000; Wang, 2000).

covering the entire platform of the conodonts of the Fanjiatun Formation.

The deposits overlying the Fanjiatun Formation were named the Yangjiagou Formation at Yangjiagou, Jiutai County in the central Jilin area (Tao et al., 1975; Guo et al., 1992). The Yangjiagou Formation is composed of grey to greenish tuffaceous breccia, conglomerate, slate and siltstone (Fig. 3A). The fossils in the formation are dominated by the bivalve *Palaeonodonta*–*Palaeomutela* Assemblage and some fossil plants such as *Noeggerathiopsis*, *Paracalamites*, etc. (Fig. 3A). The contact between the Yangjiagou Formation and the Fanjiatun Formation is unknown, but the Yangjiagou Formation is probably of Late Permian (Tao et al., 1975; Guo et al., 1992; Li in Jin et al., 2000).

### 2.2.2. Linxi area (III)

The Amushan Formation in the Linxi area, Inner Mongolia is 647 m thick and consists of a series of massive limestones containing abundant fusulinoideans, brachiopods and some corals. The basal part of the formation is dominated by the fusulinoideans *Triticites noinskyi*, *T. primigensis* and *Rugosofusulina jinheensis*, and the corals *Lithostrotionella* (*Hillia*) *formosa*, *Lomaphyllum pendulum* and *Cyathaxonia lomonsovi*, which suggest a latest Carboniferous age. On the other hand, the upper part of the Amushan Formation contains the fusulinoideans *Pseudoschwagerina alpina*, some *Triticites* species and the corals *Amygdalophylloides sinensis*, *Kionophyllidium bayanbulagense*, *Koninckocarina subventricosus*, therefore indicating an Early Permian age (EGSCLP (Editorial Group of the Stratigraphical Chart of Liaoning Province), 1978; Huang, 1993; BGMNRN, 1996).

The Amushan Formation is overlain by the Qingfengshan Formation, but their contact is unclear. The Qingfengshan Formation is between 1500 and 3000 m thick. Its lower part is dominated by slate and fine-grained sandstone containing the fossil plants *Calamites suckowii*, *Sphenopteris pseudogermanica* and *Pecopteris* sp. The upper part is composed of tuffaceous breccia, conglomerate and siltstone yielding the brachiopods *Waagenoconcha* sp., *Neochonetes* sp., *Marginifera* sp., etc. (Fig. 3B). The Qingfengshan Formation is conformably overlain by the Dashizhai Formation (EGSCLP, 1978).

The Dashizhai Formation is a series of slightly metamorphic intermediate to acidic lava, rhyolite and volcaniclastics intercalated with some sandstone (Fig. 3B). Two brachiopod assemblages were recognized by Li in Jin et al. (2000). The lower is the *Anidanthus aagardi*–*Yakovlevia mammatata* Assemblage and the upper is the *Anidanthus ussuricus*–*Marginifera morrissi*–*Permudaria* Assemblage. These two assemblages are completely correlatable with those of the Xiujimqinqi Formation in the Xiujimqinqi area, Inner Mongolia described below. In addition, the corals *Bradyphyllum*, *Tachylasma* and ammonoid *Popanoceras* were recorded. Therefore, the age of the Dashizhai Formation is probably Roadian to Wordian.

The overlying Huanggangliang Formation was subdivided into two members. The lower member is 450 m and composed

of dark grey marble, limestone and calcareous sandstone; and the upper member is 1007 m thick and composed of grayish green sandstone, conglomerate, tuffaceous siltstone interbedded with slate (EGSCLP, 1978). This formation contains the fusulinoidean *Pseudodoliolina ozawai*, the corals *Lophophyllidium pendulum*, *Tachylasma magnum* and *Bradyphyllum obscurum*, and the brachiopods *Yakovlevia mammatiformis*, *Marginifera gobiensis*, *Spiriferella keilhavii* and *Kochiproductus* cf. *porrectus* (Fig. 3B). These fossils were also reported from the Jisu Honguer Formation in the Zhesi area. Therefore, the Huanggangliang Formation is most likely to be Maokouan in age (EGSCLP, 1978; Huang, 1993).

The Huanggangliang Formation is unconformably overlain by the terrestrial Linxi Formation (Fig. 3B). This formation contains the non-marine bivalve *Palaeomutella*–*Palaeonodonta* Assemblage and the northern Angaran plants *Supaia*, *Iniopteris*, *Callipteris* and *Noeggerathiopsis* (EGSCLP, 1978; Huang, 1993) and has been assigned to the Lopingian (Late Permian).

## 2.3. Altaid Belt in Northeast China (IV)

### 2.3.1. Zhesi area, Inner Mongolia (IV)

In the western part in the Altaid Belt in Northeast China, the Permian strata and faunas in the Zhesi area, Inner Mongolia have been intensively studied (Berkey and Morris, 1927; Chao, 1927; Grabau, 1931; Li and Gu, 1976; Li, 1980; Li et al., 1980; 1982b; Ding et al., 1985; Liu and Waterhouse, 1985; Leven et al., 2001; Wang and Zhang, 2003).

The Permian deposits were subdivided into the Baotege (=Hugete Formation of Ding et al., 1985), the Jisu Honguer and the Yihewusu formations, in ascending order (Fig. 4A). The underlying strata are not exposed in the Zhesi area. At a regional scale, the undifferentiated Carboniferous–Permian deposits in the Zhesi area were named the Amushan Formation (BGMNRN, 1991, 1996), and are similar in both lithology and faunas to other areas in Northeast China.

The contact between the Baotege Formation and the undifferentiated Carboniferous–Permian strata is probably unconformable (Ding et al., 1985; BGMNRN, 1991, 1996) or faulted (Leven et al., 2001). The Baotege Formation in the Zhesi area is 700–1000 m thick and composed mainly of conglomerate, coarse-grained sandstone, calcareous sandstone, silty slate and some metamorphosed crystalline limestone and limestone lenses (Ding et al., 1985). Abundant *Monodioxodina* species were found in the calcareous sandstone of this formation. In addition, the brachiopods *Yakovlevia unsinuata*, *Waagenoconcha humboldti* and *Anidanthus nasus*, etc. and the ammonoid *Tainoceras* were recorded (Ding et al., 1985). Ding et al. (1985) established the *Monodioxodina* Zone to represent the Baotege Formation and considered to be correlatable with the Roadian *Cancellina* Zone in South China as the *Monodioxodina* fauna is associated with *Parafusulina*, *Verbeekina*, *Yangchiella* and *Pseudodoliolina* cf. *ozawai* in some other localities (Ding et al., 1985, p. 23). However, Ueno and Tazawa (2003) considered that the *Monodioxodina*

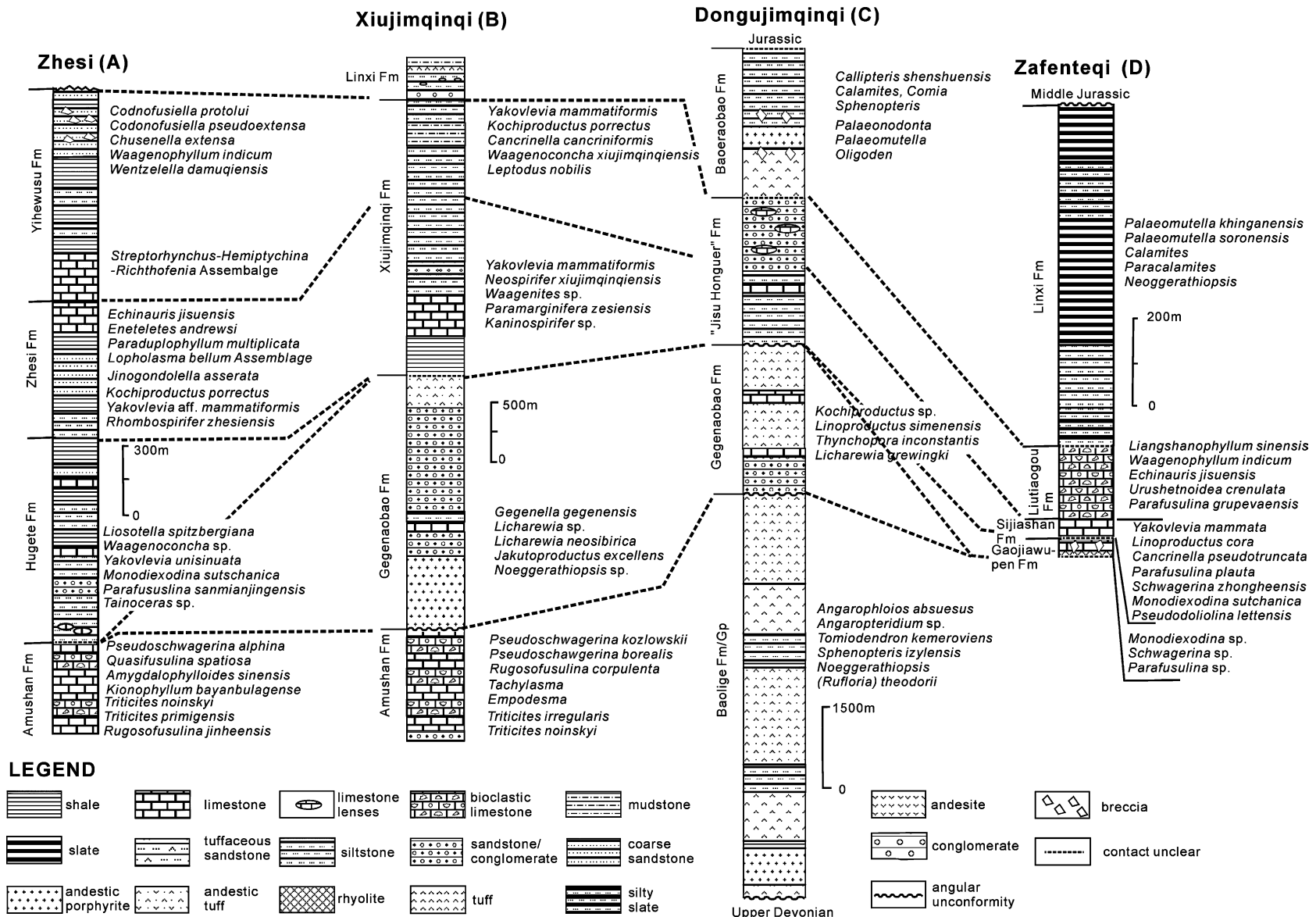


Fig. 4. Permian stratigraphical columns from the Altaid Belt (IV) (data after EGSCIM, 1978; Li et al., 1982b; 1983; Ding et al., 1985; Huang, 1986; 1993; BGMRNM, 1991; 1996; Tazawa et al., 2001; Shi et al., 2002; Wang, 2004).



*sutschanica*–*Pseudodoliolina lettensis* Zone in Northeast China is early Murgabian (=early Wordian) in age.

The Baotege Formation is conformably overlain by the Jisu Honguer Formation, which is about 555 m thick (Ding et al., 1985). Fusulinoideans are common in the upper part of the Jisu Honguer Formation. Ding et al. (1985) proposed the *Schwagerina*–*Codonofusiella* Zone for the Jisu Honguer and the overlying Yihewusu formations. The fusulinoidean species in the underlying *Monodiexodina* Zone in the Baotege Formation had completely disappeared in the *Schwagerina*–*Codonofusiella* Zone (Ding et al., 1985; Leven et al., 2001).

Brachiopods are very abundant in the Jisu Honguer Formation and have been extensively studied (Li and Gu, 1976; Zhan and Li, 1979; Li et al., 1982b; Liu and Waterhouse, 1985; Ding et al., 1985; Wang and Zhang, 2003). Li and Gu (1976); Zhan and Li (1979) and Li et al. (1982b) proposed four brachiopod assemblages for the Jisu Honguer Formation. An integrated brachiopod assemblage, the *Spiriferella*–*Kochiproductus* Assemblage, was proposed by Duan and Li in Ding et al. (1985). The characteristic elements of the *Spiriferella*–*Kochiproductus* Assemblage include *Waagenoconcha sinuate*, *Kochiproductus maximus*, *Anidanthus graciosus*, *Yakovlevia mammatiformis*, *Spiriferella voluta*, *Kaninospirifer adpressum*, *Rhambospirifer zhesiensis*, etc. Manankov (1999) suggested that this assemblage is of Ufimian–Kazanian (Wordian) age.

Corals from the Jisu Honguer Formation were studied by Ding et al. (1985). They are dominated by solitary forms. For instance, *Plerophyllum crassoseptatum*, *Tachylasma zhesiensis*, *Tachylasma variabile* are associated with some tabulates such as *Protomichelinia mandulaensis* and *Pseudofavosites finitimus minor* (Ding et al., 1985).

The largely Wordian age for the Jisu Honguer Formation has been recently supported by conodonts (Wang et al., 2004). The conodonts from the upper part of the Jisu Honguer Formation are characterized by a majority of smooth forms of *Jinogondolella aserrata* (= *Mesogondolella aserrata*), therefore strongly suggesting that the upper part of the Jisu Honguer Formation yielding the conodonts is of Wordian age (Wang et al., 2004).

The overlying Yihewusu Formation is 874 m thick and its lower part is dominated by reddish and grey thick massive limestone and breccia, and its upper part is mainly composed of coarse quartzose sandstone and greenish shale interbedded with limestone lenses (Fig. 4A). Fusulinoideans occurring near the top of the formation are represented by *Boutonia* sp., *Lantschichites* sp., *Codonofusiella protolui*, *Codonofusiella pseudoextensa*, *Sichotenella maichensis*, *Pseudofusulina quasipactiruga*, *Chusenella extensa*, etc. (Ding et al., 1985; Leven et al., 2001). The listed pseudofusulines and *Chusenella* forms are identical or very similar to those known from the vicinity of Ankara in Turkey (Skinner, 1969), where they occur with typical Midian *Yabeina* and highly evolved *Neoschwagerina* forms indicating that the age of the Yihewusu Formation is most likely Capitanian (Leven et al., 2001). This age determination is more or less supported by the age of the stratigraphically underlying Jisu Honguer Formation, which is constrained to Wordian by the conodonts (Wang et al., 2004).

Rugose corals in the Yihewusu Formation are represented by the compound *Waagenophyllum* and *Wentzelella*. Brachiopods are characterized by their mixed character between the antitropical (*Waagenoconcha humboldti*, *Horridonia morrissi*) and the Tethyan affinities, but with more Tethyan elements (e.g. *Richthofenia cornuformis*, *Enteletes andrewsi*) (Ding et al., 1985).

Late Permian deposits are unknown in the Zhesi area. The Yihewusu Formation is directly overlain by Jurassic deposits.

### 2.3.2. Xiujiinqi area, Inner Mongolia (IV)

Permian strata in the Xiujiinqi area, Inner Mongolia are subdivided into four Formations, the Amushan, Gegenaobao, Xiujiinqi and Linxi Formations in ascending order (Fig. 4B). The Amushan Formation is similar to that in the central Jilin area in lithology and biostratigraphical contents. The overlying Gegenaobao Formation is more than 1300 m thick and a sequence of acidic to intermediate volcanics, volcanoclastics and a minor amount of carbonate rocks and calcareous sandstone (BGMRNM, 1991, 1996). Both marine and non-marine fossils occur in the Gegenaobao Formation. The brachiopods *Jakutoproductus* sp., *Streptorhynchus anomalus*, *Licharewia neosibirica* and *Gegenella gegenensis*, and the fossil plant *Noeggerathiopsis* sp. are reported (BGMRNM, 1991). The brachiopods indicate broadly an age from Artinskian to Roadian (Shi et al., 2002).

The Gegenaobao Formation is overlain by the Xiujiinqi Formation, which is more than 2200 m and subdivided into two parts (BGMRNM, 1991). The lower part is more than 1036 m and dominated by chert followed by bioclastic limestone interbedded with chert. The upper part of the formation is about 1200 m thick and mainly composed of dark grey siltstone. Brachiopods occur throughout the formation, but are concentrated mainly in several major horizons (BGMRNM, 1991; Shi et al., 2002). The brachiopods in the Xiujiinqi Formation have been studied by many different authors (Li et al., 1982b; 1983; Shi et al., 2002). The common species include *Anemonaria sublaevis*, *Spiriferella keilhavii*, *Kaninospirifer* sp. (Shi et al., 2002) and *Waagenoconcha xiujiinqiensis*, *Kochiproductus porrectus*, *Yakovlevia mammatiformis*, *Licharewia multiplicata* and *Attenuatella xiujiinqiensis*, etc. (Li et al., 1982b).

The Xiujiinqi Formation is followed by the Linxi Formation, which is mainly composed of the dark silty slate and shale containing the non-marine bivalves *Palaeomutella khingaensis*, *P. soronensis*, and the fossil plants *Calamites*, *Paracalamites*, *Noeggerathiopsis*, etc. This formation is probably Lopingian in age (BGMRNM, 1991; Li in Jin et al., 2000).

### 2.3.3. Dongujimqinqi area, Inner Mongolia (IV)

The undifferentiated Carboniferous–Permian Baolige Formation/Group in the Dongujimqinqi area, Inner Mongolia is 7574 m thick and characterized by terrestrial volcanoclastic deposits (BGMRNM, 1991), which are composed mainly of andesite, andestic basalt, tuffaceous breccia interbedded with tuffaceous slate and sandstone, and contain abundant fossil

plants (Huang, 1993). The fossil plants from this formation/group include *Angarophloios abscurus*, *Angaropteridium* sp., *Tomiodendron kemeroviensis*, *Cardioneura* sp., *Sphenopteris izylensis*, *Ginkgophyllum ussovii*, *Noeggerathiopsis* (*Rufloria*) *theodorii*, etc., which are dominated by the northern Angaran elements (Huang, 1993). The Baolige Formation/Group may be partly of Early Permian age (Fig. 4C).

The overlying Gegenaobao Formation (=Yanchibeishan Formation) disconformably overlies the Baolige Formation/Group. The Gegenaobao Formation consists of andesite, tuffaceous sandstone, siltstone and conglomerate interbedded with some limestone (EGSCIM (Editorial Group of Stratigraphical Chart of Inner Mongolia), 1978; BGMRNM, 1991). A small brachiopod fauna including *Kochiproductus* sp., *Linoproductus simenensis*, *Rhynchopora inconstantis* and *Licharewia grewingki* was described by Tazawa et al. (2001). In addition, the fossil plant *Noeggerathiopsis* sp. was recorded (BGMRNM, 1991). The Gegenaobao Formation was considered to be correlatable with the Chihsian in South China (Tazawa et al., 2001).

The overlying deposits are mainly composed of feldspathic sandstone, muddy siltstone and thick conglomerate intercalated with limestone, which were assigned to the 'Jisu Honguer Formation' (EGSCIM, 1978). However, the lithology is different from the Jisu Honguer Formation at its type locality by the dominance of feldspathic sandstone, and no fossils are recorded.

Overlying the 'Jisu Honguer Formation', the Baeraobao Formation consists of intermediate and acidic tuff, volcanic breccia and sandstone with the fossil plants *Callipteris shenshuensis*, *Calamites*, *Comia* and *Sphenopteris* and the bivalves *Palaeonodonta*, *Palaeomutezlla* and *Oligoden*. This formation is correlatable with the Linxi Formation in the Linxi area (Huang and Gu, 1987; Li in Jin et al., 2000) (Fig. 4C).

#### 2.3.4. Zafenteqi area, Inner Mongolia (IV)

The lowest Permian lithologic unit in the Zafenteqi area was named as the Gaojiawopen Formation. Its relationship with the underlying strata is unknown. Early Permian deposits have never been reported in the Zafenteqi area (Fig. 4D). Only 39 m of the Gaojiawopen Formation is exposed in the Zafenteqi area and the formation consists mainly of siltstone, dark limestone intercalated with volcanics (Huang, 1993). The fusulinoideans in the formation are characterized by *Schwagerina* species in association with *Monodiexodina* (Huang, 1993), therefore suggesting a Roadian/early Wordian age.

The Gaojiawopen Formation is conformably overlain by the Sijiashan Formation, which is about 20 m thick and composed of grey medium- to thick-bedded limestone (Huang, 1993). The Sijiashan Formation contains the fusulinoideans *Monodiexodina sutchanica* and *Parafusulina plauta*; the brachiopods *Marginifera gobiensis* and *Neospirifer* sp., and the corals *Lophophyllidium carssiseptatum* and *Tachylasma* sp. (BGMRNM, 1991; Huang, 1993) (Fig. 4D), generally indicating a correlation with the Baotege and/or the Jisu Honguer Formations in the Zhesi area.

The overlying Liutiaogou Formation is about 150 m thick in the Zafenteqi area, eastern Inner Mongolia and mainly composed of dark limestone topped with breccia. The formation yields the corals *Waagenophyllum indicum*, *Yatsengia* sp., *Liangshanophyllum sinense* and *Wentzelella* sp. and *Metriophyllum chaganchuluensis*, the fusulinoideans *Skinnerina* sp., *Codonofusiella laxa*, *Reichelina* sp. and *Parafusulina gruperaensis* (BGMRNM, 1991; Huang, 1993) and the brachiopods *Eteletes andrewsi*, *Echinauris jisuensis*, *Waagenites deplanta* and *Richthofenia* sp., therefore indicating a direct correlation with the Yihewusu Formation in the Zhesi area (Fig. 4A).

The Liutiaogou Formation is followed by the terrestrial Linxi Formation containing the same bivalve *Palaeomutella*–*Palaeonodonta* Assemblage and the Angaran plants *Supaia*, *Iniopteris*, *Callipteris* and *Noeggerathiopsis* (Huang, 1986; 1993; BGMRNM, 1991) as those in the Linxi and Xiujinqin areas (Fig. 4D).

#### 2.4. Khanka Block (V)

The Khanka Block is considered to be an independent block of exotic origin (Shao et al., 1995a,b). Permian strata crop out sporadically in the block and in the Mishan–Baoqing Fault Belt between the Khanka and Jiamusi Block. The Tatouhe Formation is composed of tuffaceous silty phyllite and was previously assigned to the Upper Carboniferous by (BGMRHP) Bureau of Geology and Mineral Resources of Heilongjiang Province (1993), but may be partly Lower Permian, based on the new three-fold Permian time scale of Jin et al. (1997). The Tatouhe Formation is conformably overlain by the Erlongshan Formation, which is more than 980 m thick and mainly composed of andesite, andesitic basalt, tuffaceous conglomerate and siltstone. The bryozoans *Polypora* sp. and *Stenopora* sp. and the coral *Lophophyllidium* sp. were reported (BGMRHP, 1993) (Fig. 5).

At Pingyang Town, Jidong County, a succession of phyllite more than 691 m thick interbedded with marble, was named the Pingyangzhen Formation (BGMRHP, 1993). This formation conformably overlies the andesitic clastics of the Erlongshan Formation and contains the corals *Tachylasma* cf. *pseudocha*, *T. magnum*, *Lophophyllidium* sp., *Verbeekiella* sp., *Lytovlasma* sp. and *Paracania* sp., and the brachiopods *Spiriferella* cf. *persaranae*, *S. keilhavii* and *Neospirifer* sp. (Fig. 5). These two formations are probably Early or early Middle Permian age (Badarch et al., 2001).

The Hongyeqiao Formation at Hongyeqiao in Dongning County is more than 1309 m thick and also conformably overlies the Erlongshan Formation, with more fossils including the brachiopods *Attenuatella paraincurvata*, *Orthotichia* cf. *janiceps*, *Anidanthus* cf. *aagardi* and *Yakovlevia* sp., and the bivalves *Wikingia elegans*, *Pseudomonotis* cf. *qinlongensis* and some plant fragments. It is worth mentioning that the fusulinoidean *Yabeina?* sp. was recorded by (BGMRHP, 1993) from this formation (Fig. 5), probably indicating a partly Late Guadalupian age.

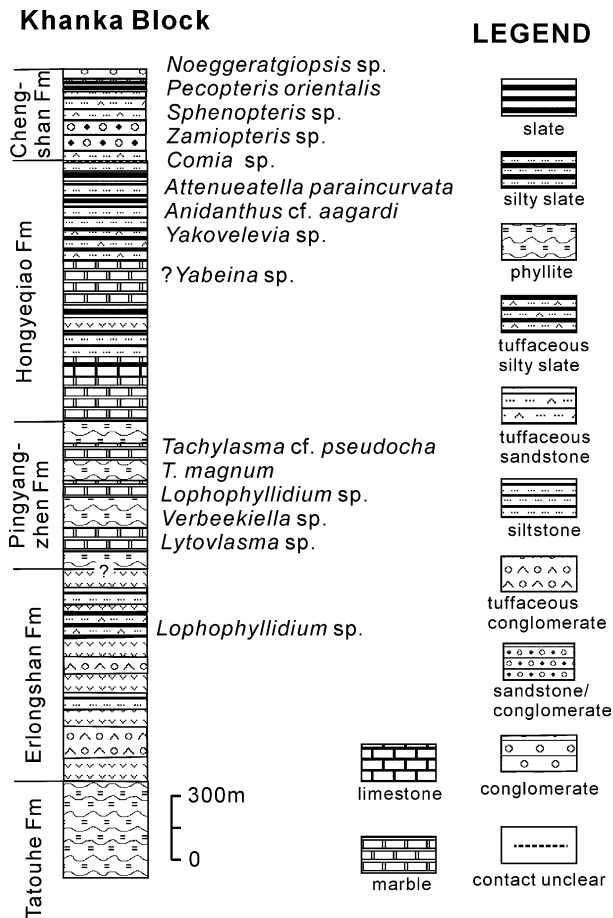


Fig. 5. Permian stratigraphical column from the Khanka Block (V) (data after BGMRHP, 1993).

The Chengshan Formation more than 414 m thick at Chengshan in Mishan County of Heilongjiang Province may represent Late Permian deposits. This Formation is a rhythmic succession of fine tuffaceous sandstone, silty slate and conglomerate containing fossil plants: *Noeggerathiopsis* sp., *Pecopteris orientalis*, *Sphenopteris* sp., *Zamiopteris* sp. and *Carpolithus* sp. In the southern part of the block, the Chengshan Formation at Dadianzi, Dongning County, Heilongjiang Province contains the fossil plants *Gigantonoclea*? sp., *Taeniopteris* sp. and *Cladophlebis* sp. (BGMRHP, 1993) (Fig. 5).

### 2.5. Jiamusi Block (VI)

Permian deposits have not been recorded from the Jiamusi Block, which is bounded by the Tongjiang–Dangbi Fault to the east, the Dunhua–Mishan Fault in the southeast and the Mudanjiang–Tangwanghe–Jielehe Fault to the west in Northeast China. This block was regarded as a part of the Khinggan–Jiamusi–Bureya Massif, which has a different tectonic evolution from the Siberian and adjacent blocks (Zonenshain et al., 1990; Cao et al., 1992).

### 2.6. Yanbian Fold Belt (VII)

The Yanbian area in Jilin Province is considered to be either an accretionary zone to the south of the Khanka Block (Shao et al., 1995b), or a collisional belt between the North China Block and the Khanka Block (Fig. 1). This belt may be divided into two tectonic zones, the eastern margin of the North China Block and the western margin of the Khanka Block (Jia et al., 2004). The Permian deposits are characterized by volcanoclastic rocks commonly with limestone blocks or conglomerate. Therefore, the Permian stratigraphy and the palaeobiogeographical affinities of the Yanbian Fold Belt are controversial (BGMRJP (Bureau of Geology and Mineral Resources of Jilin Province), 1988; Sun, 1988; Guo et al., 1992; Shao et al., 1995b; Su, 1996a; Zhang and Zhang, 1994; 1995; Shi et al., 1995; Peng et al., 1999). The Permian strata have been divided into six formations (the Shanxiuling, Dasuangou, Kedao and Miaoling Formation and the continental Kaishantun or Jiefangcun Formation in ascending order) (BGMRJP, 1988; Sun, 1988; Guo et al., 1992). However, all the six formations occur as isolated outcrops in the field and the nature of their contacts is unknown. In addition, Jia et al. (2004) recognized four different tectono-stratigraphical facies in terms of the origin and sedimentary environment of the deposits, an abyssal argillaceous rock formation, a turbidite formation, an olistostrome formation and a molasse-type formation in structurally ascending order (Fig. 6).

The Shanxiuling Formation is about 500 m thick and dominated by crystalline limestone with cherty nodules and bands with acidic tuff at the base. The formation was considered to be Late Carboniferous in age (BGMRJP, 1988; Guo et al., 1992), but the age is controversial. The fusulinoideans, including *Pseudoschwagerina leei*, *Quasifusulina* cf. *spatiosa*, *Triticites ohioensis*, *T. simplex*, *Pseudofusulina* sp., indicate strongly a Late Carboniferous to Asselian or Sakmarian age (BGMRJP, 1988; Guo et al., 1992; Shi et al., 1995). However, other fusulinoideans such as *Kahlerina ussurica* and *Verbeekina* from the limestone blocks were subsequently reported by Zhang and Zhang (1994, 1995). Those limestone blocks were considered to be olistoliths (Zhang and Zhang, 1994; 1995). The age of the Shanxiuling Formation is probably younger than Roadian, based on fusulinoideans in the olistolith limestone blocks (Zhang and Zhang, 1994; 1995; Su, 1996a) (Fig. 6).

The Dasuangou Formation at the Dasuangou Section in the Yanbian area is more than 1000 m thick. The lower 800 m of this formation is composed of grey tuffaceous breccia and sandstone with no fossils (BGMRJP, 1988; Sun, 1988; 1990). The upper 234 m of this formation has limestone intercalations, dark grey tuffaceous siltstone, calcareous siltstone with limestone lenses yielding abundant fusulinoideans and brachiopods. The fusulinoideans from the limestone lenses include *Parafusulina kaishantunensis*, *P. uniformis*, *P. regularis*, *Monodioxodina sutschanica*, *M. raphidiformis*, *Pseudofusulina* cf. *hunanensis*, *Chusenella tenuis*, *Metadoliolina yanbianensis*, *Pseudodoliolina ozawai*, *P. elongate*, *Codonofusiella* sp. and *Lepidolina* sp. (BGMRJP, 1988; Sun, 1988, 1990). In the above list, *Parafusulina kaishantunensis*, *P.*

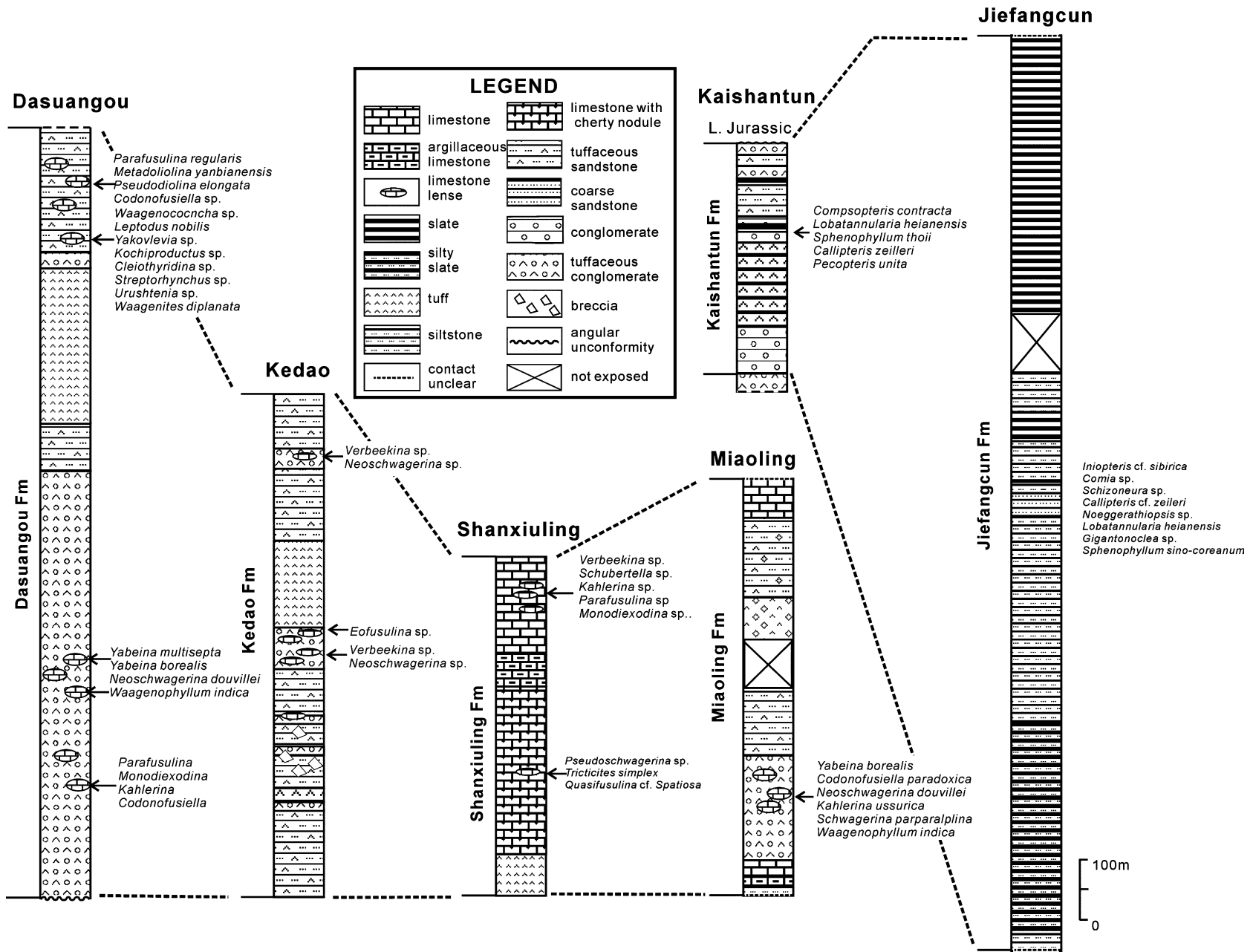


Fig. 6. Permian stratigraphical columns from the Yanbian Fold Belt (VII) (data after BGMRJP, 1988; Sun, 1988; Guo et al., 1992; Zhang and Zhang, 1994, 1995; Shao et al., 1995b; Su, 1996a; Peng et al., 1999).

*uniformis*, *P. regularis*, *Monodiexodina sutschanica*, *M. raphidoformis* and *Pseudofusulina* cf. *hunanensis* are very common in the Wordian strata of Northeast China, whereas *Chusenella tenuis*, *Metadoliolina yanbianensis*, *Codonofusiella* sp. and *Lepidolina* sp. are indicative of Capitanian age. Sun (1990) recognized two fusulinoidean zones in the Dasuanguou Formation, the *Parafusulina* Zone in the lower and the *Pseudodoliolina* Zone in the upper. The *Parafusulina* Zone consists mainly of species of Schwagerinidae including *Parafusulina kaishantunensis*, *P. uniformis*, *P. regularis*, *Monodiexodina* sp. and *Pseudofusulina* cf. *hunanensis* (Sun, 1990), therefore, generally suggesting a Wordian age. However, it is unknown whether the limestone lenses containing these fusulinoideans are olistolith blocks or not. On the other hand, the upper *Pseudodoliolina* Zone consists mainly of *Metadoliolina yanbianensis*, *Metadoliolina lepida*, *Chusenella tenuis*, etc., which probably indicate a late Capitanian age. In addition, some Late Carboniferous or Early Permian olistolith limestone blocks about 10 m thick with the fusulinoideans *Triticites*, *Pseudoschwagerina* were also reported from the Dasuanguou Formation. These blocks imply that the Dasuanguou Formation is similar to the Shanxiuling Formation in lithology and fossil content (Shao et al., 1995a, p. 135). The brachiopods reported from the Dasuanguou Formation, including *Waagenoconcha abichi*, *Leptodus* sp., *Kochiproductus* sp., *Transennatia gratiosa*, *Cancrinella cancriniformis*, *Yakovlevia* sp., *Waagenites diplanata* and *Urushitenoidea* sp. are mostly from the dark siltstone, probably suggesting autochthonous deposits (Sun, 1990). These brachiopods are common in the Late Guadalupian in Northeast China. Thus, the Dasuanguou Formation is most likely to be of Middle to Late Guadalupian age (Fig. 6).

The Miaoling Formation refers to a suite of dark tuffaceous sandstone with limestone intercalations, at its type locality faulted against both the Shanxiuling Formation and the Kedao Formation, therefore, the stratigraphical relationships are unknown. This formation is more than 815 m thick and is dominated by tuffaceous sandstone, tuff intercalated with crystalline limestone cropping out as small isolated hills and boulders. In limestone breccias, the fusulinoideans including *Yabeina* cf. *hayasakai*, *Neoschwagerina* sp., *Colania* cf. *douvillei*, *Schwagerina* cf. *pseudocompacta*, *Codonofusiella* sp. and *Parafusulina* sp., the brachiopods *Leptodus*, *Neospirifer*, *Yakovlevia*, *Spiriferella* and *Marginifera*, and the coral *Waagenophyllum indicum* (BGMJRJP, 1988; Li in Jin et al., 2000). The fusulinoideans in the Miaoling Formation were assigned to the *Neoschwagerina* Zone (Li in Jin et al., 2000) and generally suggest a Late Guadalupian, probably Wordian or early Capitanian age. Therefore, the Miaoling Formation is largely or partly equivalent to the Dasuanguou Formation (Fig. 6).

The Kedao Formation is widely distributed in the Yanbian area (Su, 1996a) and was informally subdivided into the Lower Kedao Formation and the Upper Kedao Formation by the local geological team. The Lower Kedao Formation has subsequently been called the Shanguqi Formation, and the upper Kedao Formation has been called the Tanqian Formation by

the BGMJRJP (1997). However, these two formations were combined into the Kedao Formation by Jin et al. (2000). The redefined Kedao Formation is probably another comparable lithological unit to the Dasuanguou Formation or the Shanxiuling Formation. It is characterized by turbidite deposits consisting of grey to dark purple tuffaceous breccia, dark grey siltstone and tuff, commonly intercalated with allochthonous limestone blocks or layers containing the Late Guadalupian fusulinoideans *Verbeekina*, *Neoschwagerina*, *Yabeina* and *Schwagerina*, and also Late Carboniferous limestone fragments (Su, 1996a, p. 61). Therefore, the Kedao Formation is equivalent to or younger than Capitanian (Fig. 6).

The Sidonggou Formation proposed by Sun (1988) is dominated by fine- to coarse-grained tuffaceous sandstone, silty slate and breccia and is probably a synonym of either the Kedao Formation or the Miaoling Formation because of their similar lithologies. The faunas of the Sidonggou Formation have been poorly studied, only some large *Parafusulina* and the brachiopod '*Spirifer*' are recorded (Sun, 1988).

In the Yanbian area, the Kedao Formation is overlain by the molasse-type Kaishantun Formation, which is the uppermost unit of the Late Permian (Lopingian) deposits. The Kaishantun Formation is about 350 m thick at Kaishantun and consists of grey or greenish tuffaceous conglomerate, graded sandstone and thin-bedded siltstone containing abundant fossil plants and carbonaceous shale (BGMJRJP, 1988). The conglomerate is composed of subrounded, but poorly sorted fragments, and consists mainly of piedmont alluvial deposits in which gravels derived from the Proterozoic Seluohe Group granitic gneiss and the Qinglongcun Group biotite gneiss are included. This implies that they were derived from those continental sources during the orogeny occurring at the end of the Late Permian (Jia et al., 2004). The floras in the formation are dominated by Cathaysian elements such as *Sphenophyllum thonii*, *S. sino-creanum*, *Paracalamites stenocostatus*, *Lobatannularia heianensis*, *Compsopteris contracta* and *Fascipteris hallei* (Sun, 1988) intermingled with some northern Angaran elements such as *Callipteris zeilleri* and *Pecopteris unita* (BGMJRJP, 1997). The Jiefangcun Formation at Jiefangcun in Hunchun County, Jilin Province is considered to be equivalent to the Kaishantun Formation (Shi, 1985; Guo et al., 1992; Su, 1996a,b) (Fig. 6). Peng (1996); Peng et al. (1999) claimed that brachiopods and marine bivalves suggest an earlier age, but no fossil list has been published.

## 2.7. Nadanhada Terrane (VIII)

The Nadanhada Terrane is a typical disrupted Mesozoic terrane in the northwestern region of the Circum-Pacific. It is markedly different from the Jiamusi Block to the west and the Khanka Block to the south and is composed principally of Permian–Carboniferous limestone and basalt, Triassic bedded chert and middle Jurassic siliceous shale, all enclosed within younger Late Jurassic–Early Cretaceous clastics (Mizutani et al., 1989). Permian fusulinoideans were first recognized in the terrane, and Li et al. (1979) named the fusulinoidean-bearing strata the Erlianqiao and Dongdagou formations. On

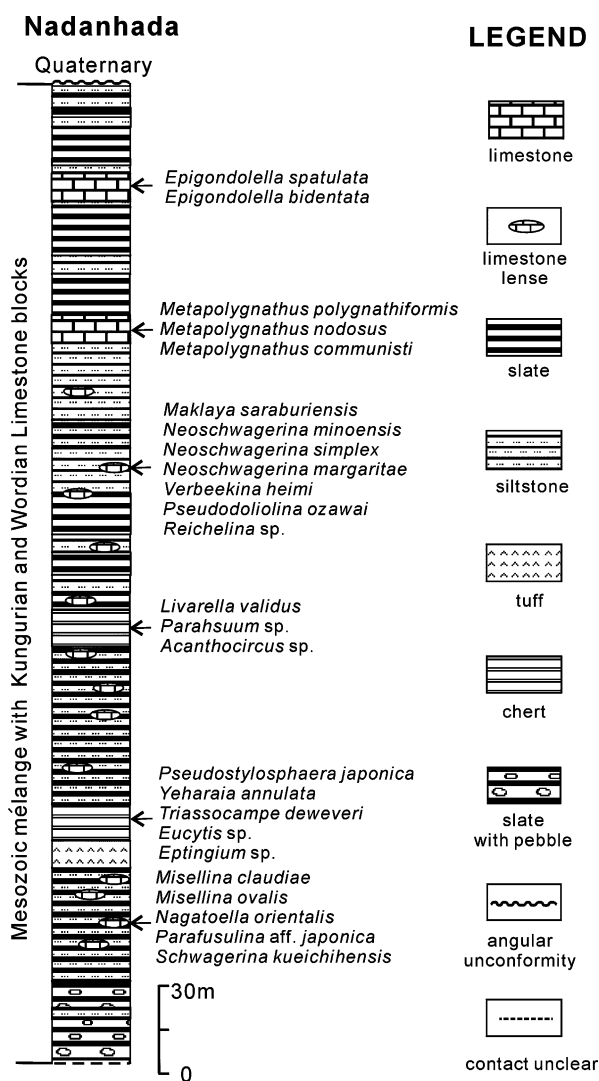


Fig. 7. Mesozoic mélangé with Permian limestone blocks in the Nandanhada Terrane (VIII) (fossil assemblages are not in sequences).

the other hand, Wang et al. (1986) discovered Late Triassic conodonts from bedded limestone with chert intercalations, and Kojima and Mizutani (1987) reported Middle Triassic and Middle Jurassic radiolarians from the chert. Therefore, those fusulinoidean-bearing limestone blocks have subsequently regarded as the exotic blocks within a Late Jurassic–Early Cretaceous mélangé, similar to the mélangé in the Mino Terrane in central Japan (Mizutani et al., 1989; Zhang et al., 1989; Shao et al., 1990; 1991).

Permian fusulinoideans in the limestone blocks of the Dongdagou Formation were subsequently described by Han (1985) and may, respectively, belong to the *Misellina claudiae* Zone and the *Neoschwagerina* Zone. Therefore, some of the limestone blocks are Kungurian or Wordian in age (Han, 1985) (Fig. 7).

## 2.8. Xing'an Block (IX)

The Xing'an Block comprises the Great Xing'an Range and the Halar Basin. Zonenshain et al. (1990) considered that

the Xing'an Block and the Siberian Continent or the central Mongolian Massif may be tectonically correlated. Permian deposits are not reliably known from the Xing'an Block. Only the undifferentiated Carboniferous–Permian Xinyigenhe Formation was described by BGMHRP (1997). This formation is 359 m thick and composed mainly of sandstone, conglomerate and sericite slate. It contains the fossil plants cf. *Angaridium* sp. and *Noeggerathiopsis* sp., and was considered to be equivalent to the Baolige Formation/Group in the Dongujimqinqi area (BGMHRP, 1997).

## 2.9. Songliao–Zhangguangcai Block (X)

The Songliao–Zhangguangcai Block is occupied by the Songliao Basin and the Zhangguangcai Range formed in the Late Mesozoic, which is the most important base for the oil industry in China. The Songliao Basin is covered by huge Mesozoic oil-bearing deposits; therefore, Permian rocks mostly do not outcrop (Fig. 1). However, the Permian deposits are documented in the eastern Zhangguangcai Range area. The Yangmugang Formation is 355–1100 m thick and composed of slate, fine sandstone, conglomerate and tuffaceous sandstone (Huang, 1980; Guo et al., 1992). According to Huang (1980), this formation contains abundant fossil plants including *Noeggerathiopsis subangusta*, *N. latifolia*, *Zamiopteris* cf. *glossopteroides*, *Nuropteris orientalis*, *N. dichotoma*, *Angaridium* cf. *mongolicum* and *Crassinervia kuznethkiana*, etc. (Fig. 8) and probably ranges from Late Carboniferous to Early Permian.

The overlying Yuquan Formation is more than 439 m thick and consists of pale grey, thick marble and crystalline limestone containing the rugose corals *Cyathocarinia tuberculata*, *Timorphyllum* aff. *patokense* and *Lophophyllidium crassisepatum*, and the brachiopods *Spiriferella simplex*, *Marginifera typica*, *Yakovlevia mammatiformis* and *Kochiproductus porrectus* (Guo et al., 1992; BGMHRP, 1993) (Fig. 8). The brachiopods are largely correlatable with those of the Jisu Honguer Formation in the Zhesi area and therefore imply a Wordian age.

The Yuquan Formation is followed by the Tumenling Formation, which represents a succession consisting of slate, fine sandstone interbedded with limestone. Brachiopods from the Tumenling Formation are characterized by *Leptodus nobilis*, *Liosotella spitzbergiana*, *Kochiproductus porrectus*, *Uncinulina timorensis* and *Waagenoconcha purdoni* (Guo et al., 1992) (Fig. 8), which are comparable with those of the Yihewusu Formation in the Zhesi area, therefore probably indicate a Capitanian age.

The overlying Sanjiaoshan Formation at Tieli County, Heilongjiang Province can be subdivided into two parts. The lower part is about 880 m thick and composed of muddy and carbonaceous slate, siltstone and sandstone with abundant fossil plants, and the upper part is 450 m thick and dominated by andesitic porphyrite intercalated with some phyllite and siltstone (Guo et al., 1992). The fossil plants include *Callipteris shenshuensis*, *C. pseudoshenshuensis*, *Comia shenshuensis*, *Noeggerathiopsis* cf. *angustifolia*, *Compsopteris tchirkovae*,

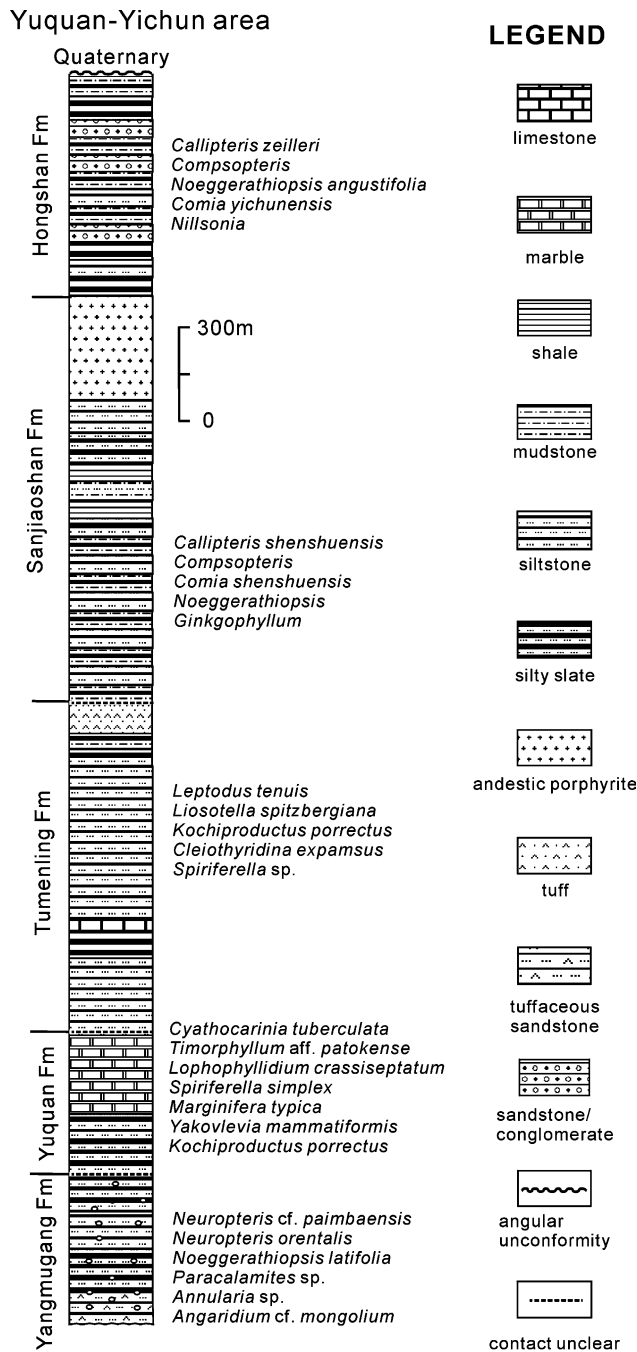


Fig. 8. Permian stratigraphical column from the Songliao–Zhangguangcai Block (X) (data after Huang, 1980; Guo et al., 1992; BGMRHP, 1993).

*Supia tieliensis*, *Rhipidopsis xing'anensis*, *Xinganphyllum inaequale*, etc. (Guo et al., 1992). The Sanjiaoshan Formation is partly correlatable with the Linxi Formation in the Manchuride Belt and the Kaishantun Formation in the Yanbian Fold Belt. The Hongshan Formation (Guo et al., 1992; BGMRHP, 1993) with the similar lithology and floras in the Yichun area, Heilongjiang Province is either equivalent to or slightly younger than the Sanjiaoshan Formation. Both of them represent molasse-type volcanoclastic deposits in the Late Permian (Fig. 8).

### 3. Biozonation and correlation

Based on the above descriptions and discussions, it can be summarized that the Early and Middle Permian strata in Northeast China are dominated by brachiopods, corals, fusulinoideans, occasionally associated with ammonoids, conodonts and bivalves (Table 1). The Late Permian Lopingian deposits are characterized by fossil plants and some non-marine bivalves and fusulinoideans in allochthonous limestone blocks. Table 1 provides a summary of key data of Northeast China derived from fusulinoideans, brachiopods, fossil plants, conodonts, ammonoids and bivalves. Table 2 provides a summary of the correlation of different lithological units in Northeast China.

#### 3.1. Conodonts

Conodonts play an important role in the subdivision and correlation of the Permian System. All the GSSPs ratified by IUGS in the Permian System are defined by conodonts. However, only two conodont faunas have been found in the Permian of Northeast China (Wang, 2000; Wang et al., 2004). The conodont fauna reported from the Fanjiatun Formation in the central Jilin area by Wang (2000) is considered to be equivalent to the *Jinogondolella asserata* Zone by Wang (2000); Wang et al. (2004). However, Mei and Henderson (2002) assigned the conodont fauna to the Roadian, based on the full serration on the platform of the conodonts. The conodonts from the upper part of the Jisu Honguer Formation were assigned to the *Jinogondolella asserata* Zone by Wang (2000); Wang et al. (2004) and are therefore of Wordian age (Jin et al., 1997; Wardlaw, 2000).

#### 3.2. Fusulinoideans

Fusulinoidean zonation in Inner Mongolia was first established by Han (1981); Xia (1981), and serves as an important reference for the correlation of Permian stratigraphy in Northeast China. The Amushan Formation and its equivalents contain two broad fusulinoidean zones, the lower *Triticites* Zone and the upper *Pseudoschwagerina* Zone, which are correlatable with those in the Maping Formation of South China. The well-recognized *Misellina claudiae* Zone in the lower part of the Chihhsia Formation of South China has been known from the Sanmianjing Formation at Kangbao, Hebei (Han, 1981; Xia, 1981; Li, 1986), the Shoushangou Formation in central Jilin (Tao et al., 1975; Yin, 1995) and the exotic Dongdagou Limestone in the Nadanhada Terrane (Han, 1985). The *Misellina claudiae* Zone in Northeast China is characterized by abundant *Parafusulina* species, some *Schwagerina* species and a few *Chusenella* species. In addition to the zonal species, the other commonest elements include *Misellina ovalis*, *Parafusulina splendens*, *Schwagerina tschernyschewi*, *Chusenella sinensis*, etc.

Above the *Misellina claudiae* Zone, the Roadian–early Wordian strata in Northeast China are characterized by containing a *Monodiexodina* fauna (Han, 1980, 1981; Xia,

Table 1. Permian biozonation in Northeast China

Period	Series	stage	conodonts	fusulinoids	ammonoids	bivalves	brachiopods	corals	plants	
Permian	Lopingian	Changhsingian				Palaeonodonta- Palaeomutella Assemblage			Comia-Callipteris- Nephropsis-Pecopteris -Noeggerathiopsis Assemblage	
		Wuchiapingian				?		Waagenophyllum- Wentzelella Assemblage	?	
	Guadalupian	Capitanian	?	Schwagerina ulanqabensis- Codonofusiella pseudooextens Subzone Yabeina-Lepidolina Assemblage	Timorites		Richthofenia cornuformis- Enteleles andrewsi- Notothyris nucleolus Assemblage			
		Wordian	Jinogondolella asserata	Schwagerina quasiregularis- Codonofusiella simplicata Subzone Neoschwagerina Zone	Roadoceras- Waagenoceras- Stacheoceras Assemblage	Cyrtostrota jisuenensis Palaeolima turcoplicata Paralaloden cf. olseini	Yakovlevia gigantesca- Rhombospirifer zhesiensis Assemblage Waagenoconcha neimongolica- Spiriferella salteri Assemblage	Tachylasma zhesiensis -Callophyllum sinense Pterophyllum- Szechuanophyllum Assemblage	Sphenophyllum yuliaense Annularia graciliscens Gigantococlea microphylla Tingia carbonica	
	Roadian	?	Monodioxodina sutschanica- Pseudodololima leitensis Zone	Popanoceras Tainoceras zhesiense	?	Alispiriferella neimongolensis- Spiriferella magna Assemblage			Neuropteris- Lobatanularia- Gigantococlea- Tingia Assemblage	
	Cisuralian	Kungurian			Agathiceras-Artinskia- Paracitites- Parastacheoceras Assemblage		Yakovlevia mamma- Anidanthus aagardi Assemblage		Polyrhecalis- Yatsengia- Chusenophyllum Cyathocarina tuberculata Timorphyllum aff. patokense Lophophyllum crassiseptatum	Noeggerathiopsis Zamiopsis Zamiopsis Sphenopteris
		Artinskian	?							
		Sakmarian								
		Asselian			Pseudoschwagerina Zone					Empodasma-Tachylasma Assemblage Carinthiophyllum- Akagrophyllum Assemblage



Table 2. Permian lithostratigraphical correlation in Northeast China

Period	Series	stage	Kangbao Hebei	Chifeng Inner Mongolia	Central Jilin	Linxi, Inner Mongolia	Zhesi Inner Mongolia	Xiujiminqi Inner Mongolia	Dongujiminqi Inner Mongolia	Zafenteqi Inner Mongolia	Yanbian, Jilin	Yuquan Heilongjiang	Khanka Block	
Permian	Lopingian	Changhsingian		Ranfangdi Formation	Yangjiagou Formation	Linxi Formation		Linxi Formation	Baeraobao Formation	Linxi Formation	Kaishantun Formation	Hongshan Formation	Chengshan Formation	
		Wuchiapingian												
	Guadalupian	Capitanian		?	?	?	Yihewusu Formation				Liutiaogou Formation			
		Wordian		Yujiabeigou Formation	Fanjiatun Formation	Huanggangliang Formation	Jisu Honguer Formation	Xiujiminqi Formation	"Jisu Honguer" Formation	Sijiashan Formation	Dasuanguo Formation Miaoling Formation Kedao Formation Shanxiuling Formation	Tumenling Formation	Hongyeqiao Formation	
		Roadian	Daheshen Formation		Dashizhai Formation	Baotege Formation			Gaojiawopen Formation	Yuquan Formation		Pingyangzhen Formation		
	Cisuralian	Kungurian	Sanmian-jing Fm Eliitu Fm	Qingfengshan Formation	Shoushangou Formation	Qingfengshan Formation			?	?		?	Yangmugang Formation	Erlongshan Formation
		Artinskian		Jiujuzi Formation					Gegengaobao Formation	Gegengaobao Formation				
		Sakmarian												
		Asselian	Amushan Formation	Shizuizi Formation	Shizuizi Formation	Amushan Formation	Amushan Formation	Amushan Formation	Baolige Group	?	?	?	Tatouhe Formation	

1981; Ueno and Tazawa, 2003). This fauna is commonly found in sandy limestone and calcareous sandstone (Ueno and Tazawa, 2003). The *Monodioxodina*-bearing horizon was assigned to the *Monodioxodina sutshanica*–*Parafusulina lettensis* Zone by Han (1981) or the *Monodioxodina* Zone by Xia (1981); Ding et al. (1985). The fusulinoidean individuals of this zone are usually very large and elongate in outline and characterized by extremely high abundance. The commonest elements include *Pseudodoliolina. ozawai*, *Codonofusiella*, *Parafusulina*, etc. in addition to the nominal species. The *Monodioxodina* fauna has also been reported from the Midian in Russian Far East (Sosnina, 1960), the Tenglonggongba Formation in Ngari region, southwestern Tibet (Wang et al., 1981; Zhang, 1991), and the Capitanian Ochiai Formation in southern Kitakami, northeast Japan (Ehiro and Misaki, 2004). However, the *Monodioxodina* Zone in Northeast China is considered to be of Wordian age because of the co-occurrence of *Pseudodoliolina lettensis* and *Codonofusiella* species (Ueno and Tazawa, 2003).

The Wordian–Capitanian strata in the Zhesi area have been assigned to the *Schwagerina*–*Codonofusiella* Zone by Xia (1981); Ding et al. (1985). This zone was subdivided into two subzones, the lower *Schwagerina quasiregularis*–*Codonofusiella simplicata* Subzone and the upper *Schwagerina quasipactiruga*–*Codonofusiella pseudoextensa* Subzone. The lower subzone is largely Wordian in terms of the associated conodonts and the upper zone is probably Capitanian. The *Neoschwagerina* Zone and the *Yabeina* Zone in the Yanbian Fold Belt and the Nadanhada Terrane are correlatable with those in the Maokouan in South China.

### 3.3. Brachiopods

Brachiopods are the most abundant fossil group in the Permian of Northeast China. Early Permian Cisuralian brachiopods have not been recorded and only a small *Dictyoclostus* Assemblage was recorded in the central Jilin area, but with no detailed species list (Guo et al., 1992). The earliest Permian brachiopod assemblage with a detailed list is from the Gegenaobao Formation in the Xiujiminqi area, Inner Mongolia (BGMNRN, 1991). The assemblage consists of *Gegenella gegenensis*, *Jakutoproductus excellens*, *Grandaurispina pustula*, *Kiangsiella subcircularia*, *Halospirifer typical*, *Parareticularia spiriferiformis* and *Licharewia neosiberica*, which has been named as the *Gegenella. gegenensis*–*Jakutoproductus. excellens* Assemblage by Li in Jin et al. (2000). This assemblage is Early Permian, but a more precise age is not available.

The Guadalupian strata in Northeast China contain abundant brachiopods (Li and Gu, 1976; Zhan and Li, 1979; Li et al., 1982b; Liu and Waterhouse, 1985; Ding et al., 1985; Wang and Zhang, 2003). Li and Gu (1976) and Li et al. (1982b) proposed four brachiopod assemblages for the Guadalupian strata in Northeast China. They are the *Licharewia grewingki*–*Neospirifer moosakhailensis* Assemblage, the *Waagenites deplanata*–*Horridonia*–*Liosotella* Assemblage, the *Anidanthus ussuricus*–*Marginifera morrisoni*–*Permudaria* Assemblage and

the *Anidanthus aagardi*–*Muirwoodia* (= *Yakovlevia*) *mammata* Assemblage, in ascending order. These four assemblages were recently revised into the following two assemblages by Wang and Zhang (2003), the *Yakovlevia gigantica*–*Rhombospirifer zhesiensis* Assemblage in the lower and the *Richthofenia cornuformis*–*Eteletes andrewsi*–*Notothyris nucleolus* Assemblage in the upper. The lower assemblage was assigned to the Wordian and the upper one to the Capitanian by Wang and Zhang (2003).

In addition, Li et al. (1982b) recognized four brachiopod assemblages based on several sections in the Xiujiminqi area, Inner Mongolia. They are the *Anidanthus aagardi*–*Yakovlevia mammata* Assemblage, the *Anidanthus ussuricus*–*Marginifera morrisoni*–*Permudaria* Assemblage, the *Waagenites. deplanata*–*Horridonia*–*Liosotella* Assemblage and *Licharewia grewingki*–*Neospirifer moosakhailensis* Assemblage, in ascending order (Li et al., 1982b). Liu and Waterhouse (1985) proposed two brachiopod assemblages, the *Yakovlevia borealis*–*Stenosisma* cf. *paucisulcata* Assemblage in the lower and the *Elivina sinensis*–*Neospirifer adpressus*–*Stenosisma* Assemblage in the upper. Recently, Wang and Zhang (2003) revised the four assemblages of Li et al. (1982b) with different representatives of brachiopods. They are the *Yakovlevia mammata*–*Anidanthus rugosa* Assemblage, the *Alispiriferella neimongolensis*–*Spiriferella magna* Assemblage, *Waagenococnha neimongolica*–*Spiriferella salteri* Assemblage and the *Yakovlevia borealis*–*Pseudomarginifera ussuricus* (= *Anidanthus ussuricus*) Assemblage, in ascending order. The above-mentioned brachiopod assemblages are probably Wordian in terms of the association with the Wordian fusulinoideans in the Jisu Honguer Formation in the Zhesi area.

### 3.4. Corals

The Early Permian (Cisuralian) corals in Northeast China have been integrated into two assemblages by Guo (1982), the lower *Carinthiaphyllum*–*Akagophyllum* Assemblage and the upper *Empodesma*–*Tachylasma* Assemblage. They correspond to the *Pseudoschwagerina* Zone.

A probably Kungurian coral assemblage was recorded from the Shoushangou Formation in the central Jilin area. This assemblage consists of *Yatsengia*, *Polythecalis* and *Chusenophyllum*, and is roughly correlatable with those of the Chihhsian in South China.

Corals are more common in Guadalupian strata. Guo (1980, 1982) recognized two assemblages, the lower *Lytovlasma*–*Szechuanophyllum* Assemblage and the upper *Waagenophyllum*–*Wentzelella* Assemblage. However, Guo (1980, 1982) assigned the lower assemblage to the Chihhsian. The other associated fossils, including fusulinoideans and brachiopods, suggest a Roadian or Wordian age for this assemblage. In the Zhesi area, four assemblages were recognized by Ding et al. (1985). They are the *Plerophyllum crassoseptatum*–*Tachylasma zhesiensis*–*Tachylasma variabilis* Assemblage, the *Protomichelinia mandulaensis*–*Pseudofavosites finitimus* minor Assemblage, the *Carinoverbeekiella sinensis*–*Pseudowaagenophyllum vesiculosum*–*Diphycarinophyllum*

Assemblage from the Jisu Honguer Formation and the *Waagenophyllum virgalense mongoliense*–*W. stereoseptatum*–*Wentzelella* Assemblage from the Yihewusu Formation (Ding et al., 1985). The lower three assemblages are Wordian in terms of the associated conodonts, and the uppermost assemblage is possibly Capitanian in age.

### 3.5. Ammonoids

Ammonoids have only been sporadically reported in the Permian of Northeast China. An assemblage represented by *Agathiceras*, *Artinskia*, *Paracelites* and *Parastacheoceras* was documented by Yin (1995). *Agathiceras* has been reported from the Maping Formation and the lower part of the Chihsia Formation in South China. *Artinskia* is common in the Artinskian and *Paracelites* is very common in the Maokouan in South China. This assemblage generally suggests a Kungurian age. This age determination is also supported by the associated fusulinoideans and brachiopods. In addition to the above ammonoid fauna, *Daubichites* and *Medlicottia* have been recorded from the Wujiatun Formation (=Jisu Honguer Formation) at Debuosi, Keyouqi and the Jisu Honguer Formation at Sirenwendouer, Abahanaerqi in Inner Mongolia (Liang, 1981). *Waagenoceras* has been recorded from the Fanjiatun Formation. *Waagenoceras* has been selected as the ammonoids zonal element of the Wordian Stage in the three-fold time scale (Jin et al., 1997), but it has a long range from Roadian to earliest Wuchiapingian.

### 3.6. Bivalves

Bivalves have not been well studied in the marine Permian in Northeast China. Zheng (1993) described a diverse marine bivalve fauna from the Yujiabeigou Formation. This fauna consists of species of 16 genera and are dominated by *Cyrtorostra jisuensis*, *Palaeolima furcuplicata* and *Myalinella verneuili*, etc. The bivalve fauna is considered to be equivalent to that of the Jisu Honguer and Yihewusu formations (Yin, 1995). Non-marine bivalves are very common in Late Permian continental deposits in Northeast China, and have been recognized as the *Palaeonodonta*–*Palaeomutella* Assemblage.

### 3.7. Plants

Fossil plants are mainly found in the Carboniferous–Early Permian Baolige Group and the Late Permian Linxi, Kaishantun and Jiefangcun formations in Northeast China. The floras in the Baolige Group are dominated by *Angaridium*, *Angaropteridium*, *Neuropteris* and *Noeggerathiopsis*, which range from Late Carboniferous to Early Permian (Huang, 1993). The Wordian Yujiabeigou Formation yields 48 plant species (Huang, 1993). The flora is dominated by *Sphenophyllum*, *Lobatannularia*, *Fasciapteris*, *Pecopteris* and *Taeniopteris*, which are completely comparable with those of the Shihezi Group of North China (Huang, 1993). The floras in the Late Permian Linxi, Kaishantun and Jiefangcun formations are dominated by *Comia*, *Callipteris*, *Rhipidopsis*, *Nephropsis*, etc.

which are all common elements of the Late Permian in Russian Far East (Huang, 1993).

## 4. Permian palaeobiogeographical division in Northeast China

The faunas and floras in the Permian of Northeast China exhibit a mixed character between the Palaeoequatorial Cathaysian Province and the Boreal Realm, which represents part of the Inner Mongolian–Japanese Transitional Zone of Tazawa (1991, 1992) or the Northern Transitional Zone of Shi et al. (1995). During the Cisuralian, the palaeobiogeographical differentiation between the Boreal Realm and the Cathaysian Province in Northeast China was not distinct. The suture between the Manchuride and Altaid Belts (Fig. 1) has been generally regarded as the suture between the North China and Siberian Blocks (e.g. Tang, 1990; Sengör et al., 1993; Chen et al., 2000). However, the fusulinoidean composition of the *Pseudoschwagerina* Zone in the Amushan Formation or its equivalents in the area south to the suture including the Manchuride Belt, the continental margin of the North China Block, the Yanbian Fold Belt, and the areas north to the suture including the Zhesi and Xiujimqinqi area in Inner Mongolia is comparable with that in South China (BGMNRN, 1991, 1996) (Tables 1 and 2). The Early Permian Cisuralian deposits in the Xing'an Block are poorly known, therefore very difficult to characterize the palaeobiogeographical affinities of this block. Nevertheless, the continental deposits of the Baolige Formation/Group with typical Angaran floras and Boreal forms dominate faunas in the Dongujimqinqi area in eastern Inner Mongolia, implying that the palaeobiogeographical division between the Boreal Realm and the Palaeoequatorial Cathaysian Province lay to the north of the suture.

By the late Early Permian, the palaeobiogeographical division between the Boreal Realm and the Cathaysian Province appears to lie along the Xar Moron River (Tazawa, 1991, 1992) (Fig. 1). The floras to the south of the suture are characterized by the Cathaysian elements such as *Emplectopteris minima*, *Gigantonoclea borealis*, *Taeniopteris norini*, *Sphenophyllum yujaensis*, etc. (Shi, 1985; Huang and Gu, 1987; Huang, 1993). The marine benthic faunas are characterized by the Tethyan *Misellina*–*Neoschwagerina*–*Yabeina* faunas (Li, 1986; Han, 1985). Brachiopods appear mixed between Boreal/bi-temperate and Cathaysian affinities, as indicated by the presence of a few Boreal elements such as *Yakovlevia* in the Yujiabeigou Formation in the Chifeng area, but dominated by the Tethyan elements.

In contrast, the marine faunas north to the Xar Moron River indicate a more Boreal character in terms of the presence of the many Boreal or antitropical brachiopods including *Anemonaria*, *Anidanthus ussuricus*, *Kochiproductus*, *Rhambospirifer*, *Spiriferella*, *Waagenoconcha* and *Yakovlevia* (Li and Gu, 1984) and the solitary corals such as *Lytovlasma*, *Tachylasma*, *Sezuanophyllum* and *Plerophyllum*. Conodonts exhibit a cool/cold character as indicated by the small serrated elements (Wang, 2000; Mei and Henderson, 2002; Wang et al., 2004). Fusulinoideans are characterized by the bi-temperate

*Monodioxodina* fauna in the middle Guadalupian and the *Schwagerina*–*Codonofusiella* fauna in the middle and late Guadalupian and the absence of large Tethyan *Neoschwagerina* fauna (Ding et al., 1985; Guo, 1995). It is worth mentioning that the fauna from the Yihewusu Formation contains more Tethyan-type brachiopods in the *Richthofenia. cornuformis*–*Enteletes andrewsi*–*Notothyris nucleola* Assemblage and the compound corals in the *Waagenophyllum*–*Wentzelella* Assemblage and probably indicates a warming event in the late Guadalupian.

This palaeobiogeographical disparity continued into the Late Permian. Although no marine fossils have been recorded in the Late Permian in Northeast China, the floras in the Altaid Belt, the Khanka Block and the Yanbian Fold Belt are dominated by the Angaran elements occasionally with a few Cathaysian elements such as *Lobatannularia* and *Schizoneura* (Xu and Liu, 1981; Huang and Gu, 1987; Huang, 1974; 1993; Peng, 1996; Peng et al., 1999). In the northern margin of the North China Block, the floras are characterized by the Cathaysian elements such as *Lobatannularia ensifolia*, *Sphenophyllum sino-coreanum*, *Neuropteridium coreanicum* and *Gigantopteris nicotianaefolia* (Shi, 1985; Huang, 1993).

The faunas from the exotic limestone blocks in the Nanhada Terrane include the Late Carboniferous fusulinoid *Fusulinella*, the coral *Donophyllum* and *Koninckocarina*, the Early Permian *Pseudoschwagerina* and *Misellina*, and the Middle Permian *Verbeekina* and *Pseudodoliolina* (Li et al., 1979), therefore characterizing a typical palaeoequatorial character.

## 5. The implications for tectonic evolution

Since the northern margin of the North China Block and the Manchuride Belt both contain marine Tethyan faunas and Cathaysian floras, the Manchuride Belt was accreted to the North China Block in pre-Permian time. The Manchuride and Altaid Belts contain similar Middle and Late Permian mixed faunas and floras, indicating that these blocks had amalgamated before the mid-Permian and implying that the Palaeo-Asian Ocean had almost disappeared by this time. During the Permian, these two belts formed a single terrane and became the site of a volcanic arc, indicated by abundant subaerial volcanism (Guo et al., 1991). During the Late Permian the Palaeo-Asian Ocean was mostly closed, as Late Permian molasse-type deposits are widespread and Triassic deposits are absent in Northeast China. However, the eastern end of the Palaeo-Asian Ocean probably remained open until the end of the Permian, as the the Late Permian Kaishantun Formation in the Yanbian Fold Belt is similar to the Toyoma Formation in Northeast Japan which is considered to have been deposited by sedimentary gravity flows in a deep-sea environment (Tazawa, personal communication).

The collision between the Khanka and North China Blocks probably also took place during the Late Permian, as evidenced by the emplacement of syncollision granites (Jia et al., 2004) and deposition of the molasse-type deposits of the Kainshan-tun/Jiefangcun Formation. However, the origins of the Khanka

Block and the Yanbian Fold Belt are controversial. Tazawa (1992); Shi et al. (1995) considered that the Yanbian Fold Belt to be part of the Central Asian Orogenic Belt (CAOB) and the biotas are transitional between the Boreal Realm and Palaeoequatorial Cathaysian Province. In contrast, Shao et al. (1995a,b) considered that the Khanka Block and the Yanbian Fold Belt originated from Gondwanaland and was located near the Yangtze Block during Permian time (Shao et al., 1995b, p. 554). The main evidence used by Shao et al. (1995a,b) to suggest the position of the Khanka Block is based on the presence of the *Monodioxodina* and *Timorites* faunas in the block, or in the belt surrounding the block. These two faunas are known from the Guadalupian of Tibet (Wang et al., 1981) and Timor (Haniel, 1915), which were situated on the northern peri-Gondwanan margin during the Permian time. However, the two faunas are also known from the Guadalupian in the other areas of Northeast China, Russian Far East and South Kitakami, NE Japan. Therefore, the occurrence of the *Monodioxodina* and *Timorites* faunas can be easily interpreted as a bi-temperate/bipolar distribution of the faunas, a well-known phenomenon during Permian time (e.g. Shi et al., 1995).

From the lithologies and the presence of Jurassic radiolarians the Nanhada Terrane is very similar to the Mino Terranes, the Ryukyu Arc and the Philippines. This terrane therefore formed part of the accretionary complexes, which developed along the eastern continental margin of Asia during Mesozoic time (Mizutani et al., 1989). This terrane is related to Mesozoic tectonic movements in the western circum-Pacific region and was accreted to the Asian continent in its present position during Late Jurassic to Early Cretaceous time (Mizutani et al., 1989; Kojima et al., 2000).

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