

Permian geodynamic setting of Northeast China and adjacent regions: closure of the Paleo-Asian Ocean and subduction of the Paleo-Pacific Plate

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Abstract

Northeast China and adjacent regions are located in the central East Asian continent and consist tectonically of both the Paleo-Asian and Paleo-Pacific orogens between the Siberian platform and Sino-Korean (North China) block. This paper discusses some hotly-debated issues concerning the Permian geodynamic setting of these regions, based on a comprehensive analysis of available geological, geochemical, paleobiogeographical and paleomagnetic data. Spatial and temporal distribution of ophiolites and associated continental marginal sequences, Permian sedimentary sequences, spatial distribution and geochemistry of Permian magmatic rocks, and the evolution of paleobiogeographical realms imply: (1) that the Permian marine basins in northeast China and adjacent regions include remnants of the Paleo-Asian Ocean in southeastern Inner Mongolia and central Jilin Province, and active continental margins of the Paleo-Pacific Ocean; (2) that the suture between the Siberian and Sino-Korean paleoplates was finally emplaced in the Permian and is located in areas from Suolunshan (Solonker) eastwards through regions north to the Xar Moron river in southeastern Inner Mongolia, and then central Jilin province to the Yanji area; and (3) that the Permian crustal evolution of northeast China and adjacent regions, as well as parts of the Siberian paleoplate, was influenced by subduction of the Paleo-Pacific oceanic plate. Finally, the Permian tectonic framework and paleogeography of northeast China and adjacent regions in central East Asia are discussed briefly, and Early and Late Permian palinspastic reconstruction maps are provided.

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Keywords: Permian; geodynamic setting; Paleo-Asian Ocean; Paleo-Pacific Ocean; northeast China and adjacent regions; central East Asia

1. Introduction

Asia is the youngest continent on planet Earth and is composed of a mosaic of pre-Sinian blocks (older than 625Ma) and Phanerozoic orogens (Li et al., 1982; Sengor and Natal'in, 1996; Li, 2004b). The region between the Indian Shield and Siberian platform is composed, in turn from north to south, of the Mongolian-Okhotsk orogens, (part of the Paleo-Pacific orogens), from central Mongolia to the Okhotsk sea; Paleo-Asian orogens, from Tianshan to Changbai Mountains; Sino-Korean and Tarim blocks; Paleo-Tethyan orogens, from Kunlun Mountains to central Korean peninsula; Yangtze blocks; Tethyan orogens from southwest China to Turkey (Fig. 1). The formation and tectonic evolution of these orogens followed contraction and closure of their precursory oceans, i.e. the Paleo-Pacific, Paleo-Asian, Paleo-Tethyan, and the Tethyan oceans, respectively. In the eastern Asian continent,

Mesozoic and Cenozoic circum-Pacific orogens (PO in Fig. 1), which originated from subduction of the Pacific Plate under the Asian continent, are superimposed on the various above-mentioned blocks and orogens.

Northeast China and adjacent regions between the Mongolian-Okhotsk orogen and the Sino-Korean Block in the central East Asian continent include the eastern segment of the Paleo-Asian orogens; they are composed of Paleozoic accretional margins of the Siberian Platform and the Sino-Korean Block and their collisional belt, and surrounded by the Paleo-Pacific orogens including the Mongolian-Okhotsk orogen in the north and Russian Far East orogens in the east. Geologists from China and other countries have studied the tectonic division and evolution, sedimentology, magmatism, structural deformation, paleobiogeography, and paleomagnetism of these regions. However, there are markedly conflicting interpretations on some questions, such as the tectonic affiliation of the Permian marine basin in the eastern Paleo-Asian orogens, the position and timing of the collision between the Sino-Korean and Siberian paleoplates, and the relationship

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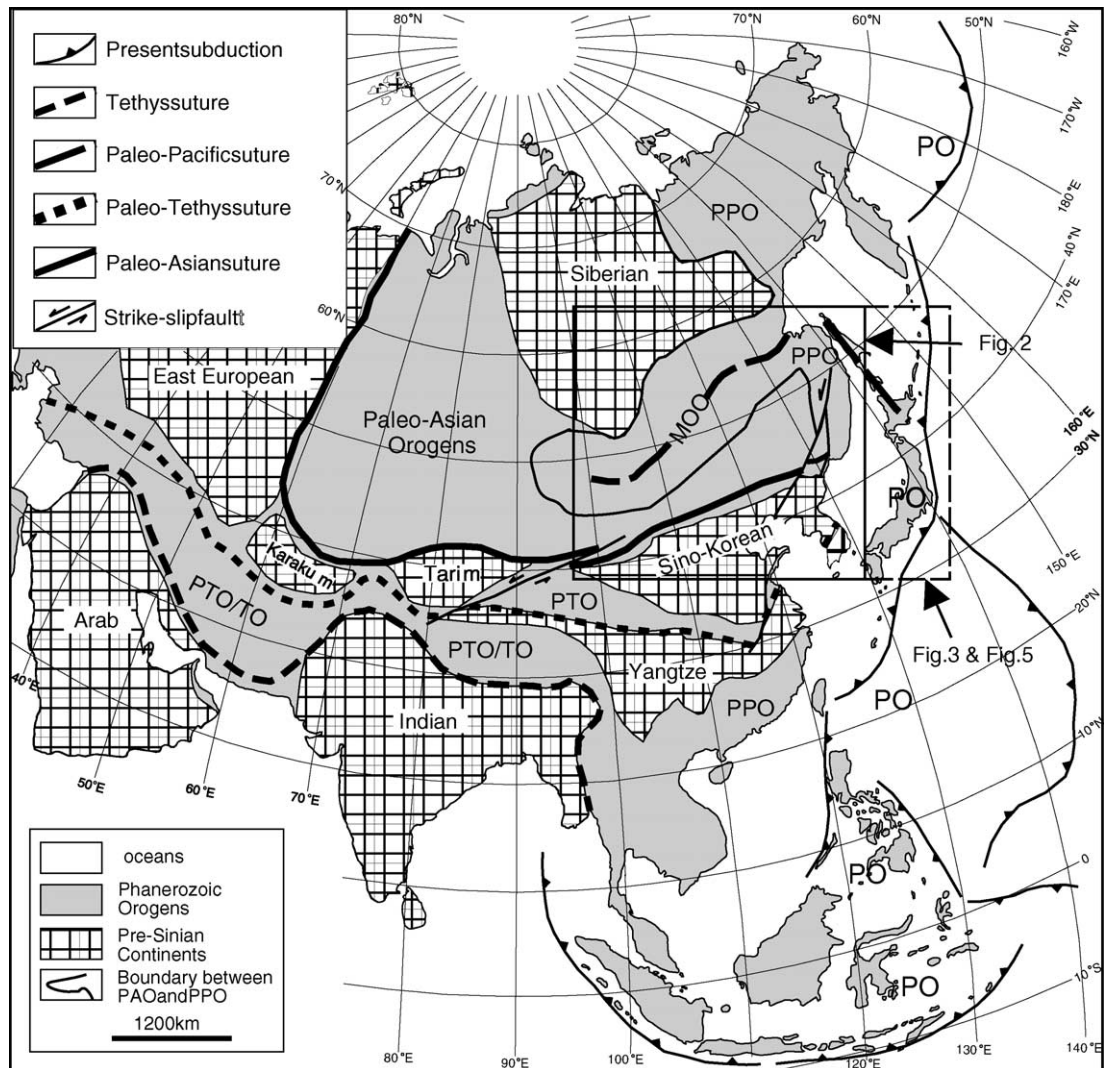


Fig. 1. Tectonic framework of Asia showing the location and extension of the main sutures of various oceanic basins. PPO: Paleo-Pacific orogens, MOO—Mongolian-Okhotsk orogenic belt, PTO—Paleo-Tethyan orogens, TO—Tethyan orogens, PO—Circum-Pacific orogens of the East Asia.

of the orogeny of the Mongolian-Okhotsk orogen to geological processes in northeast China and adjacent regions.

The aim of this paper is to review and discuss these questions, especially the geodynamic setting of the Permian geological processes in the region on the basis of an integrated analysis of geological, geophysical and paleobiogeographical data. In this paper, the Paleo-Asian Ocean is defined as the Paleozoic oceanic basin between the Siberian Platform on the one side and the Tarim and Sino-Korean blocks in the opposite side, as suggested by Dobretsov et al. (1995); and the Paleo-Pacific Ocean, which includes the Khangai-Khantey ocean (Sengör et al., 1993; Sengör and Natal'in, 1996), is regarded as the precursor of the Mongolian-Okhotsk orogens, and the Kula-Pacific Ocean.

2. Tectonic divisions and the feature of main tectonic units

Various tectonic divisions of northeast China and adjacent regions have been put forward by geologists from both China and other countries (Huang et al., 1980; Ren et al., 1999;

Li et al., 1982; Sengör et al., 1993; Sengör and Natal'in, 1996; Li, 1998). However, the division suggested by Li et al. (1982) is oversimplified; the division proposed by Sengör and Natal'in (1996) is too detailed and complicated to be supported by available data; it also suffers from a lack of kinematic data from the major faults. Based on the available data, a new tectonic division is proposed in Fig. 2. In this division, two kinds of tectonic units are distinguished: i.e. Pre-Sinian blocks or massifs, which are defined as crustal areas with Archean-Paleoproterozoic or Middle Proterozoic-Early Neoproterozoic basements; and the Phanerozoic orogenic belts of various ages, consisting of Phanerozoic island arcs, accretional or collisional complexes, and reworked Pre-Sinian massifs. The features of the main tectonic units of the region are stated briefly, from south to north, as follows.

The Sino-Korean Block is located in the south of northeast China. Its geometry is the same as the Sino-Korean paraplatform (Huang et al., 1980), or the North China Craton in other accounts, and its northern boundary is marked by the northern Sino-Korean marginal fault (Huang et al., 1980; Ren et al.,

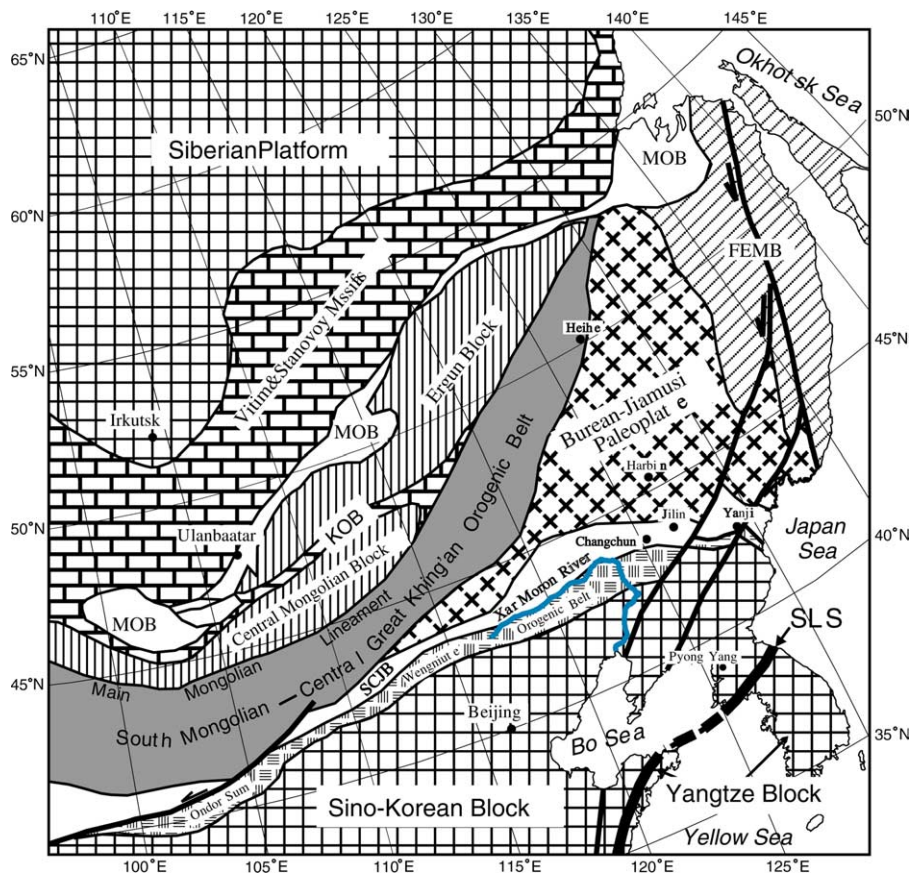


Fig. 2. Tectonic divisions of northeast China and adjacent regions. MOB—Mongolian-Okhotsk orogenic belt, KOB—Kelulun ophiolite belt, SCJB—Suolunshan-Central Jilin orogenic belt, SLS—Sulu suture between Sino-Korean and Yangtze paleoplates.

1999). Mesoproterozoic and lower Neoproterozoic, Cambrian through Middle Ordovician, and Upper Carboniferous through Triassic sedimentary cover lies in turn over the Archean-Paleoproterozoic metamorphic basement of the block (Huang et al., 1980; Ren et al., 1999; Li, 2004b). An intermediate-acid plutonic belt of Late Carboniferous through Triassic ages occurs on the northern margin of the block (Zhang, 1984; Shao, 1986; Xu, 1987; Wang, 1990; Wang et al., 1991; Tang, 1992; Mu and Yan, 1992; Nie et al., 1993, 1994, 1995; Peng and Zhong, 1995; Jia and Wu, 1995; Leng et al., 1996; Zhong et al., 1996; Chen et al., 1997; Zhang, 1998; Yan et al., 2000; Zhang et al., 2003a,b; Xu et al., 2003; Tao et al., 2003a); and Jurassic and Cretaceous terrestrial volcano-sedimentary strata and contemporary plutons, and Cenozoic intra-continental basins and mantle-derived basalts overlie the cover and basement of the eastern block (Cheng, 2000).

The Ondor Sum-Wengniute orogenic belt (Fig. 2) is located between the Xar-Moron and northern Sino-Korean marginal faults, and is composed of Cambro-Ordovician accretionary complexes and overlying Carboniferous and Permian volcano-sedimentary sequences and intrusive plutons, similar to those of active continental margins (Wang et al., 1991; Tang, 1992). The Ondor Sum ophiolites of Late Neoproterozoic age (Tang et al., 1983; Peng, 1984; Shao, 1986; 1991; Wang et al., 1991; Nie et al., 1995; Zhang et al., 1996; Wu et al., 1998; Zhang and Wu, 1998) and Early Paleozoic blueschists (Tang, 1992; Tang and

Yan, 1993) are tectonically packaged in the Early Paleozoic accretionary complexes.

The Suolunshan-Central Jilin orogenic belt (SCJB in Fig. 2) is located between the Xar Moron fault and the Aerdenggelemiao-Hegenshan ophiolite belt in southeast Inner Mongolia and from Changchun through Jilin to the Yanji area in central Jilin Province, and consists mainly of Carboniferous and Permian marine volcano-sedimentary strata. Some massifs, such as the Xilinhot massif, which consist mainly of Paleoproterozoic metamorphic complexes (Xiao et al., 1995; Xu et al., 1996), and some ophiolites are enclosed within the belt (Wang and Liu, 1986; Wang et al., 1991).

The Burean-Jiamusi paleoplate (Fig. 2) is different both in geometry and constitution from the Burean-Jiamusi Block as described in previous literature, and is here defined as a composite paleoplate, which was amalgamated in the Early Paleozoic with both Pre-Sinian Burean, Hegang, Mashan, Khingkai, and Harbin massifs, and also the early Paleozoic orogenic belts (Li, 1995b; 1998; Song et al., 1997; Li et al., 1999a,b).

The South Mongolian-Central Great Khing'an orogenic belt extends between the Aerdenggelemiao-Hegenshan-Heihe ophiolite belt and the Main Mongolian Lineament (Fig. 2); it formed part of the Devonian-Carboniferous arc and backarc-basin systems surrounding the Siberian paleoplate (Li et al.,

1990; Li, 1991, 1995a, 2004a; Kulkov, 1993; Zhu and Liu, 1995; Lamb and Badarch, 1997, 2001; Li et al., 2003), and today it constitutes the collisional belt of Early Carboniferous age between the Siberian and Burean-Jiamusi paleoplates. The Zhalantun, Tsagaan Uul, and Hutag Uul massifs, which formed the basements of Devonian island arcs, were incorporated into the South Mongolian-Central Great Khing'an orogenic belt and reworked during the Early Carboniferous collisional orogeny (Li, 1998; Badarch et al., 2002).

The Central Mongolian and Ergun blocks are surrounded by the South Mongolian-Great Khing'an Belt in the south and the Mongolian-Okhotsk Belt in the north, and are separated from each other by the Kelulun ophiolite belt (KOB in Fig. 2). The Central Mongolian block extends westwards, then turns northwestwards in the center of Mongolia to encircle the Mongolian-Okhotsk Belt, and there it is separated from the Tuva Block by the Dzhida orogenic belt of Cambrian to Ordovician age (Al'mukhmedov et al., 1996). Archean and Paleoproterozoic metamorphic complexes have been recognised in the Central Mongolian Block (Makarychev, 1997; Dergunov et al., 1997; Kozakov et al., 2003; Wang et al., 2005), and Paleoproterozoic complexes in the Ergun Block (BGMRHLP, 1993; Wang et al., 2005). Along the northwestern margins of the Central Mongolian and Ergun blocks, Devonian through Jurassic plutons and volcanic rocks, similar to those of active continental margins, have been distinguished (Sorokin et al., 2002; Li et al., 2004a).

The Mongolian-Okhotsk orogenic belt (MOB in Fig. 2) extends from central Mongolia northeastwards to the Upper Heilongjiang region, and then turning into a nearly west-east direction to the Okhotsk sea. This belt consists mainly of Sinian (Vendian) to Permian volcano-sedimentary rocks in the northern Mongolia and Transbaikalian region of Russia, and Sinian (Vendian) to Cretaceous rocks in its eastern segment. Fragments of Jurassic foreland basins occur in Transbaikalian and in the Upper Heilongjiang areas on its southern side (He et al., 2005). Devonian, Carboniferous, Permian, Triassic to Jurassic magmatic zones encircled the belt.

The Early Paleozoic accretionary belt of the Siberian platform, including the Vigim and Stanovoy massifs and Siberian platform, occur north of the Mongolian-Okhotsk Belt (Fig. 2). The Russian Far East Mesozoic orogenic belt (including the easternmost Heilongjiang province of China; FEMB in Fig. 2), part of the Paleo-Pacific orogens, surrounds the Burean-Jiamusi paleoplate. These two belts are both beyond the scope of this paper.

The above-mentioned tectonic units may be merged into three Late Paleozoic plates, the Siberian (Siberian platform and its southern marginal orogenic belts and blocks/massifs), Sino-Korean (Sino-Korean Block and its northern marginal orogenic belt), and Burean-Jiamusi paleoplates. The collisional orogeny between the Siberian and Burean-Jiamusi paleoplates took place along the Hegenshan-Heihe ophiolite belt in the Early Carboniferous, forming the South Mongolian-Great Khing'an orogenic belt (Li, 1995b; 1998). The position and timing of the collisional orogeny (suturing)

between the Siberian and Sino-Korean paleoplates will be discussed later in this paper.

3. The Permian marine basin of eastern Inner Mongolia and central Jilin province of Northeast China: a residual ocean or an extensional (rift) basin?

The southeastern Inner Mongolian Autonomous Region and central Jilin Province of northeast China, i.e. the Suolunshan-Central Jilin orogenic belt, is the region where the Paleozoic marine sedimentary basin of the eastern Paleo-Asian ocean finally disappeared. The tectonic setting of this Permian marine basin was considered to be part of a Late Paleozoic geosyncline in the Chinese geological literature until the end of the 1970s (Huang et al., 1980). Following the advent of plate tectonic theory, Li et al. (1982) reconstructed the tectonic framework and evolution of the Asian continent since the Sinian (about 625Ma), and recognized that the basin was a residual ocean that had separated the Siberian paleoplate from the Sino-Korean paleoplate, and was finally closed by the latest Permian. This conclusion was further supported by subsequent investigations into geology, paleobiogeography, and paleomagnetism (Huang, 1983; 1986; Wang and Liu, 1986; Wang et al., 1991; Li, 1985, 1987a,b, 1998; Li et al., 2004b; Wen et al., 1996; Zhang, 1997; Wang and Fan, 1997; Zhang, 1998; Su et al., 2000; Zhang et al., 2000; Kravichinsky et al., 2002). However, other Chinese geologists argued in the late 1980s that the ocean between the Siberian and Sino-Korean paleoplates was closed before the Late Devonian or in the Early Carboniferous, and that the Permian marine basin in this region was a newborn rift basin with extensional tectonomagmatic activity (Zhang and Tang, 1989; Tang, 1990; 1992; Shao, 1991). Likewise, Zhang and Li (1997) considered that the marine basin was a Late Carboniferous to Permian intracontinental rifted trough with bi-modal volcanic activity.

The debate concerning the tectonic setting of the Permian marine basin of northeast China is also pertinent to such questions as when the Paleo-Asian ocean was closed in this region, and how the eastern Asian continental crust formed and evolved during the Late Paleozoic. Thus, it is indispensable to further study and discuss this issue for understanding the formation and evolution of the Asian continent. Abundant new geological and geochemical data obtained in recent years has made it possible to review and re-discuss this issue. In the following paragraphs, ophiolites and associated continental marginal sequences, sedimentary sequences of the Permian strata, geochemistry of Permian volcanic rocks, and paleobiogeographical realms of various ages in the Suolunshan-Central Jilin orogenic belt will be described. All these data support the viewpoint that the Permian marine basin in the area was a residual oceanic basin.

3.1. Ophiolites and associated continent-marginal sequences

Various ophiolite belts constitute relics of ancient oceans in northeast China and adjacent regions (Fig. 3). The spatial and temporal distributions of these belts imply that their formation

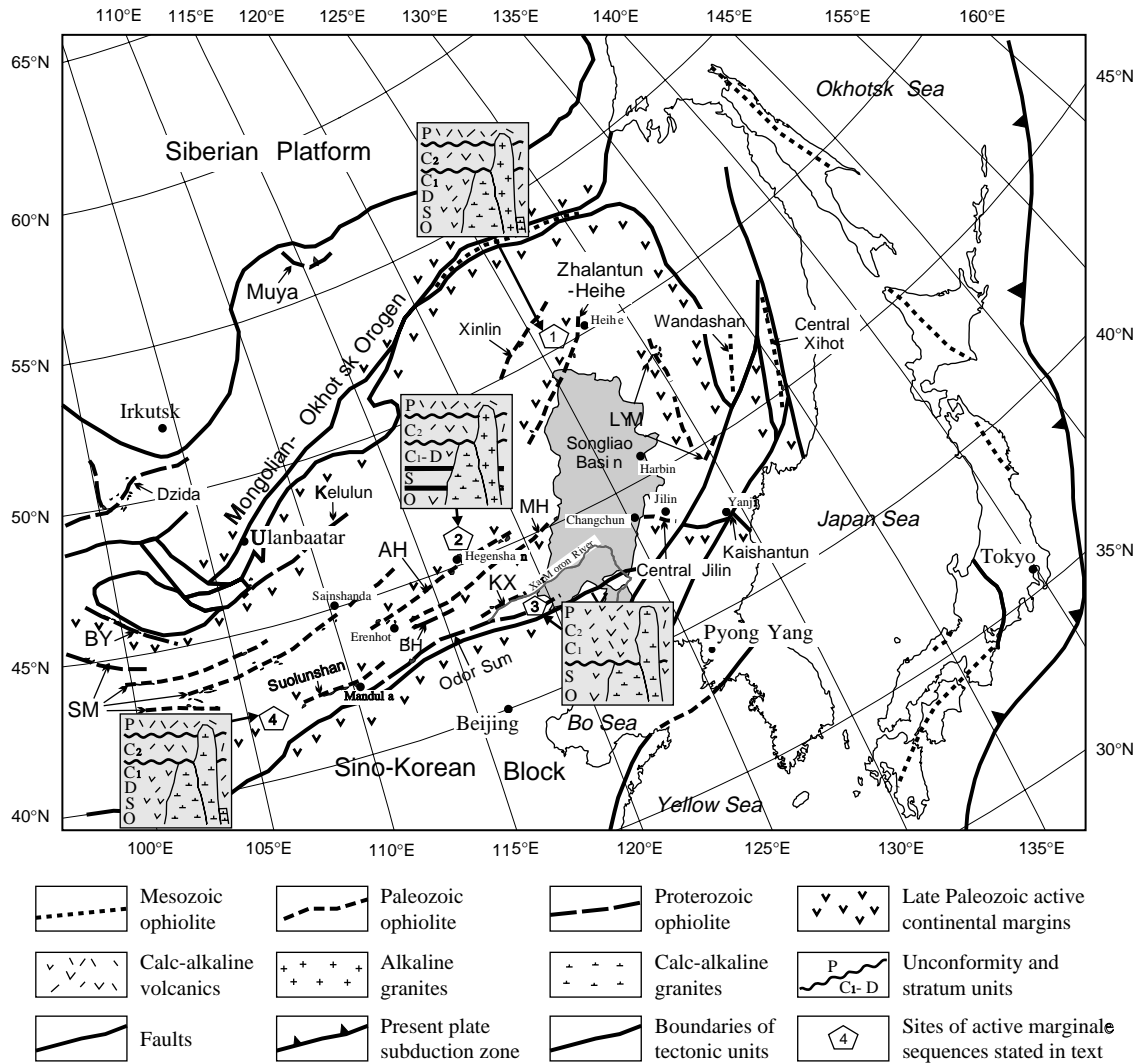


Fig. 3. Tectonic setting of Northeast China and adjacent regions, mainly showing distribution of ophiolites. The names of the various ophiolite belts in capital letters are as follows: BY—Bayan-Khongor, SM—South Mongolian, KL—Kelulun, BH—Bayan Obo-Honggermiao, AH—Aerdenggelemiao-Hegenshan, KX—Kedanshan-Xingshuwa, LYM—Luobei-Yilan-Mudanjiang. Polygons represent the sites of marginal sequences mentioned in the text and the number in them are: 1-Duobaoshan, 2-north of Hegenshan ophiolite belt, 3-North of Chifeng city, 4-Oyu Tolgoi in south Mongolia.

and emplacement were related to the evolution of the Paleo-Asian ocean and the Paleo-Pacific ocean. However, these ancient oceanic remnants form too small a part of these ancient oceanic lithospheric plates for the reconstruction of the evolutionary history of these oceans. Therefore, it is necessary to use the continental margin sequences associated with the oceanic rocks, as they can also provide information concerning the tectonic evolution of these two oceans. Of these ophiolites and associated continental marginal sequences, only those in the Suolunshan-Central Jilin orogenic belts are related to the tectonic features of the Permian marine basin of the eastern Paleo-Asian orogen, and will be described in detail in this account.

Five ophiolite belts occur in southeast Inner Mongolia, the western segment of the Suolunshan-Central Jilin orogenic belt; these are from north to south: (1) Aerdenggelemiao-Hegenshan (AH), (2) Manlaimiao-Haoertumiao (MH), (3) Bayan’Obo-Honggermiao (BH), (4) Kedanshan-Xingshuwa (KX) and (5) Suolunshan belts (Fig. 3).

Geological mapping and geophysical investigations reveal that the Hegenshan ophiolite sheet in the Aerdenggelemiao-Hegenshan belt is the largest ophiolite in northeast China, composed of serpentinized peridotites, gabbros, diabases, basalts and reddish radiolarian cherts. It was emplaced tectonically into Devonian marine volcano-sedimentary sequences and overlain unconformably by Middle Permian marine strata of the Zhesi Formation (Liu, 1983; Wang et al., 1991; Bao et al., 1994; Robinson et al., 1995; Shi and Zhan, 1996; Nozaka and Liu, 2002). Based on coral fossils and radiolarian microfossils in the associated Devonian strata and reddish cherts, Liu (1983) suggested that the age of formation of the ophiolites was Devonian. However, a whole rock Sm-Nd isochron age of 403Ma from dunite, peridotite, and gabbro samples (Bao et al., 1994) indicates that the ophiolites formed in the Silurian or earlier. Some new younger K-Ar and Ar-Ar ages from the ophiolites (Robinson et al., 1999; Nozaka and Liu, 2002) are probably overprints of Mesozoic tectono-

thermal events, as was pointed out by Zhou et al. (2002). The Aerdenggelemiao-Hegenshan belt extends from north of Erenhot city northeastward to Hegenshan, and then possibly turns northeastwards to connect to the Zhalantun-Heihe belt (Fig. 3) forming an ophiolite belt more than 1000 km long (Li, 1998). This belt is also the southern boundary of the area of the distribution of the *Tuvaella* fauna (Su, 1981). Ordovician through Early Carboniferous marine calc-alkaline volcanic and terrigenous clastic strata and acid-intermediate plutons occur in the area northwest of the Heihe city, northwest of the Zhalantun-Heihe belt (Du et al., 1988; BGMRLP, 1993); and continuous Devonian through Early Carboniferous volcano-sedimentary sequences are also exposed in the area north of the Hegenshan ophiolites (BGMRLM, 1991), implying that the ocean represented by the ophiolite belt was consumed by northwestward subduction under the active continental margin of the Siberian paleoplate during Ordovician through to Early Carboniferous times, and that the ocean was still open in the Early Carboniferous. An interesting phenomenon is the fact that no blueschist or intense structural deformation characteristic of ancient subduction zones have been reported from the Aerdenggelemiao to Hegenshan segment of the belt, implying the possibility of the emplacement of the ophiolite blocks in these areas by obduction.

The NE-extended Manlaimiao-Haoertumiao ophiolite belt (Fig. 3) is situated south of Xiwuzhumuqinqi, about 100 km south of the Aerdenggelemiao-Hegenshan belt. Serpentinite and basalt blocks have been structurally emplaced in the marine Carboniferous and Permian strata. Pillow basalts in the belt are exposed as flattened pods in grassland areas southwest of Xiwuzhumuqinqi, indicating that the belt underwent intense structural deformation (Wang et al., 1991).

The Bayan'Obao-Honggeermiao ophiolite belt (BH in Fig. 3) is exposed south of the Xilinhot massif, which is composed of Proterozoic metamorphic rocks (Xiao et al., 1995; Xu et al., 1996) intruded by Paleozoic calc-alkaline island-arc granitoids (Chen and Xu, 1996; Chen et al., 2001; Zhang et al., 2004) and unconformably covered by upper Devonian terrestrial sedimentary sequences (BGMRLM, 1991). This belt consists of ophiolitic mélanges (Wang et al., 1991; Zhang and Wu, 1999). Early in the 1980s, some blueschist outcrops were found in this belt (Hu, 1983) and an Ar-Ar age of 383Ma was obtained from glaucophane (Xu et al., 2001). Based on these data, some geologists considered that the belt is part of the Middle Paleozoic suture between the Siberian and Sino-Korean paleoplates (Tang, 1992; Xu and Chen, 1997; Xu et al., 2001). Xu and Chen (1997) suggested that the formation of this belt resulted from the northward subduction of the Paleo-Asian oceanic plate. However, Li (1987a; 1987b; 1998) based on regional geology argued that the belt marks an ancient zone of subduction under the northern margin of the Sino-Korean paleoplate. Structural data published by Davis et al. (2004) suggested that the mélangé belt consists of tectonic slices, being part of metamorphic core complexes, and the root is probably located in the area north of the island-arc granitoids. However, the occurrence of continuous Ordovician

through to Lower Carboniferous sequences in southern Mongolia and the Great and Lesser Khing'an ranges does not favor Middle Paleozoic closure of the ocean. Thus, the tectonic setting of the belt remains unresolved.

The Suolunshan ophiolite is located on the Chinese side of the boundary between China and Mongolia (Fig. 2). Its extension on the Mongolian side is called the Solonker ophiolite. There are detailed descriptions of the petrology, geochemistry and rock assemblage of the ophiolite (Zhu and Li, 1983; Shao, 1991; Wang et al., 1991; Tang, 1992). The ophiolite blocks in the belt were tectonically emplaced into Upper Carboniferous marine strata and overlain unconformably by Middle Permian marine terrigenous clastics, indicating that the ocean, precursor of the belt, had not closed in the Early Permian. The belt has been believed consistently to be the youngest of the Paleo-Asian orogens, and part of the suture marking the closure of the Paleo-Asian ocean (Li et al., 1982; Li, 1987a; 1998; Wang and Liu, 1986; Wang et al., 1991; Cao et al., 1986; Guo, 1986; Tang, 1990; 1992; Sengor and Natal'in, 1996; Xiao et al., 2003). Recent surveys of the regional geology by local geologists indicate that the belt extends eastwards to the Erdaojing area where a Permian subduction-related volcanic arc appears to have been formed north of the belt (Su et al., 2000; Tao et al., 2003b). Westwards, the belt extends along the northern margin of the Alashan massif (Wu and He, 1993), part of the Sino-Korean paleoplate, and then possibly through the Beishan Mountains into the Tianshan Mountains, or to the south of the Tarim Block in northwest China. In the Oyu Tolgoi area on the Mongolian side of the belt, there are Ordovician through to Carboniferous volcanic rocks and plutons (Perello et al., 2001), possibly forming part of a Paleozoic active continental margin. Interestingly, this belt coincides with the boundary of two Permian paleobiogeographical realms (Huang, 1983; Wang and Gao, 1999; Zhang et al., 2000).

The Kedanshan-Xingshuwa ophiolite belt (KX in Fig. 3) extends ENE, roughly along the Xar Moron River in southeastern Inner Mongolia. He and Shao (1983), and Li (1987b) described the petrological features of this belt in detail and interpreted it as a relic of the Early Paleozoic oceanic lithosphere that had been subducted southwards under the Sino-Korean paleoplate. This view was based mainly on microfossils contained in associated siliceous rocks and on regional geology. Later, Wang et al. (1991) arrived at a similar conclusion. However, in the late 1990s, based on the discovery of Permian radiolarian fossils from associated siliceous rocks in the belt, some geologists argued that the ophiolite belt is composed of the relics of Permian oceanic crust, and hence may mark the suture of the Paleo-Asian ocean (Wang and Fan, 1997). No structural data has so far been found to prove that these various kinds of rocks belong to a single tectonic slice. There is the possibility that belt consists of a structural stack of many tectonic slices of various ages. Continuous Carboniferous-Permian volcano-sedimentary sequences, reminiscent of an active continental margin setting, rest unconformably on the Early Paleozoic accretionary complexes of the Ondor Sum-Wengniute orogenic belt south of the Xar Moron river

(BGMRNMAR, 1991; Wang et al., 1991; Li, 1998). This fact, combined with the occurrence of the above-mentioned Carboniferous through to Permian volcanic rocks and plutons on the northern Sino-Korean Block, implies that the northern margin of the Sino-Korean Block was an Andean active continental margin during these periods.

Chinese geologists have long debated whether or not there are ophiolites in the central Jilin Province, eastern part of the Suolunshan-Central Jilin orogenic belt (SCJB in Fig. 2). Liu and Shan (1979), Li and Wang (1983), Jia (1988); Xu (1991) considered that there are ophiolitic fragments in the Paleozoic orogenic belt of central Jilin Province. Shao and Tang (1995) reported the occurrence of ophiolites in Kaishantun, eastern Jilin Province. However, Peng and Wang (1997) argued that those so-called ophiolites are different in rock assemblage and geochemistry from typical ophiolites in other orogenic belts in the world, although they have the features of Alpine-type ultramafic complexes. Serpentinites to the east of Changchun city (Shitoukoumen), south of Jilin city (Yanchongshan), and south of Yanji city (Kaishantun) all contain chromite, show intense structural deformation and are associated with basalts similar to MORB in chemical composition. It is therefore reasonable to suggest that those rocks may be relics of ophiolites. Recently, Wu et al. (2003) reported some blueschist facies metamorphic rocks in Kaishantun, south of Yanji city. Zhang et al. (2000) pointed out that fossils of contrasting paleobiogeographical affinities are contained in the Permian strata on either side of the Kaishantun structural belt. Paleozoic granites and Carboniferous-Permian volcano-sedimentary sequences on both sides of the belt from Changchun through Jilin and then to Yanji cities have an affinity to those of an active continental margin (BGMRJP, 1988). Late Paleozoic strata in areas south of the belt are similar in rock assemblage and paleontological fossils to those in areas south of the Xar Moron river, southeastern Inner Mongolia, suggesting that both areas formed part of an active continental margin during the Late Paleozoic.

3.2. Permian strata and sedimentary settings

Permian strata in northeast China and adjacent regions are sparsely exposed due to denudation and Mesozoic and Cenozoic cover, and are composed mainly of continental, shallow marine, and deep-water terrigenous clastic and volcanic rocks (Huang, 1982; Ding et al., 1984; BGMRJP, 1988; BGMRHP, 1989; BGMLRP, 1989; BGMRNMAR, 1991; Mueller et al., 1991; BGMRHLP, 1993; Su, 1996). Continental deposits are distributed in areas north of the Aerdenggelemiao-Hegenshan ophiolite belt and south of the Ondor Sum ophiolite belt. Permian shallow marine sedimentary sequences with minor continental interlayers occur in areas between the Kedanshan-Xingshuwa and Ondor Sum ophiolite belts. Between the Aerdenggelemiao-Hegenshan and Kedanshan-Xingshuwa ophiolite belts, Permian strata are dominated by shallow marine facies. Along the Manlaimiao-Haoertumiao and in areas close to the Kedanshan-Xingshuwa ophiolite belts, relatively deep-water strata of Permian age are

exposed in several localities (Ding et al., 1984; BGMRNMAR, 1991; Jiang et al., 1995a,b; Wang and Fan, 1997; Gao and Jiang, 1998). The occurrence of Permian radiolarian-bearing siliceous rocks north of the Xar Moron River implies that a moderate open ocean existed in the eastern Paleo-Asian orogen at that time. Very thick upper Permian terrigenous clastic strata with plant fossils were previously considered by local geologists as having been deposited in a lacustrine environment. However, sedimentological data obtained by He et al. (1997) reveal that the upper Permian strata consist predominantly of marine turbidites and that the overlapping lower Triassic strata are composed of lacustrine molasse.

In lithology, the Permian strata are characteristic of regressive sequences, as they gradually change from marine to continental facies in sedimentary environments, and from fine-grained to coarse-grained in sediment size from bottom to top. These features indicate that the Permian strata were probably deposited in a remnant sea, rather than in an extensional rifting basin. Structurally, the most intense deformational event in the area took place between the end of the Paleozoic and the beginning of the Mesozoic. These data indicate that the Paleozoic ocean of the area was probably closed in the Late Permian (Li et al., 1982; Wang et al., 1991; Mueller et al., 1991; Li, 1987a,b; 1998).

3.3. Permian paleobiogeographical realms

Various paleobiogeographical realms have been recognised in the eastern segment of the Paleo-Asian orogens from northeast China to Japan during the Paleozoic, especially during the Permian.

An Early Cambrian *Archaeocyathus* fauna is observed only in the Siberian Platform, Sayan Ranges southwest of the Siberian platform, northern Mongolia, the central segment of the Great Khing'an mountains and the Hegenshan ophiolite belt, Yichun in eastern Heilongjiang Province, and the area southeast of Khingkai Lake in the Russian Far East (Guo, 1981; Khanchuk and Belyaeva, 1993). The Middle to Late Silurian *Tuvaella* fauna is only found in areas north of the Suolunshan, Aerdenggelemiao-Hegenshan and Zhalanlun-Heihe ophiolite belts (Su, 1981; Kulkov, 1993); no similar fossils have been observed in contemporaneous strata on the Sino-Korean Block or in its northern margins (BGMRJP, 1988; BGMRHP, 1989; BGMLRP, 1989; BGMRNMAR, 1991; Liao et al., 1995). These data imply that from Cambrian through to Silurian times a wide ocean separated the Sino-Korean Block from the other paleo-continents now in east and northeast Asia.

Late Carboniferous to Permian paleobiogeographical realms in northeast China and adjacent regions include the Arctic (Boreal) faunal and Angaraland floral realms, and the Tethyan faunal and Cathysian floral realms on both north and south sides of the belt from Suolunshan, eastwards along the Kedanshan-Xingshuwu ophiolite belt, through Changchun and Jilin to Yanji cities (Huang, 1982, 1983, 1986; Xu, 1995; Peng et al., 1998; Tazawa, 1998, 2002; Zhang et al., 2000; Lin et al., 2000; Duan and An, 2001). An admixture of the two faunas is observed in the Middle Permian strata in the Mandala area

(Gao and Jiang, 1998; Wang and Gao, 1999) and Yanji area (Shi and Zhan, 1996) and a mixed late Late Permian Angaraland-Cathysian flora occurs in the area south of the Kedanshan-Xingshuwa ophiolite belt (Huang, 1983).

There are two explanations for the origin of Permian paleobiogeographical realms in northeast China and adjacent regions. Some geologists suggest that a tectonic factor is dominant in determining their occurrence (Li et al., 1982, 1983; Huang, 1983; Wang et al., 1991), while others argue that climatic and environmental factors are more important (Durante et al., 1985; Zhang, 1988; Shi et al., 1995; Shi and Grunt, 2000). Why is there no admixture between the different paleobiogeographical realms in the Early Permian and earlier strata? In combination with geological and paleomagnetic data, a tentative explanation is that a Paleozoic oceanic basin, probably connecting with the Paleo-Tethys, the Paleo-Pacific the Arctic oceans, separated the Siberian from the Sino-Korean paleoplates, but was converted into an intercontinental remnant marine basin following the northwards drifting of the Sino-Korean and other blocks in northeast China and adjacent regions at the end of the Early Permian (see also Shi, 2006).

3.4. Tectonic settings of Permian magmatic activity in the eastern Paleo-Asian orogens

Permian magmatic activity was intense and violent, and responsible for the occurrence of eruptive and intrusive rocks of various compositions in the eastern segment of the Paleo-Asian orogens in northeast China and adjacent regions. Compositional zoning from south to north for this period of magmatic activities may be observed in southeastern Inner Mongolia in the western segment of the Suolunshan-Central Jilin orogenic belt.

On the northern margin of the Sino-Korean Block, south of the Kedanshan-Xingshuwa ophiolite belt (the Xar Moron river), Permian intrusive rocks are dominated by calc-alkaline granite, with only minor granodiorite and diorite. Contemporaneous eruptive rocks are mainly composed of calc-alkaline andesites, rhyolites and minor basalts (Zhang, 1984; Wang, 1990; Wang et al., 1991; Nie et al., 1994; Peng and Zhong, 1995; Jia and Wu, 1995; Hong et al., 1995; Leng et al., 1996; Zhang et al., 1996; Zhang, 1998). A Late Triassic alkaline and alkaline-like granite belt is superimposed on these Late Paleozoic magmatic rocks (Mu and Yan, 1992; Yan et al., 2000; Tao et al., 2003a).

In the western Suolunshan-Central Jilin orogenic belt, Permian intrusive rocks are dominated by granodiorite and minor granite. Associated volcanic rocks were mainly erupted during the Early Permian and consist mainly of basalts and spilites, accompanied by only minor andesites/keratophyres and a few acid rocks. This assemblage of magmatic rocks was probably erupted in a supra-subduction zone extensional marine setting, similar to the Tertiary volcanics in central Mexico (Aguillon-Robles et al., 2001; Ferrari, 2004; Ferrari et al., 2001; Marquez et al., 1999).

Some small stocks of Early Permian alkaline granitoids are exposed in areas north of the Hegenshan ophiolite belt, and

form part of an alkaline granite mega-belt of the Paleo-Asian orogens from East Junggar in northeast Xinjiang through central Mongolia to the Great Khing'an Mountains in northeast China (Hong et al., 1991; 1995), which is superimposed on an active continental margin, with the occurrence of Carboniferous and early calc-alkaline plutonic batholiths (Hong et al., 1995). In the Permian volcanic rocks of the area alkali-enriched rhyolites are dominant (BGMARNMAR, 1991).

There are two different schools of thought among Chinese geologists regarding the tectonic setting of Permian magmatic activity. One is presented by Wang et al. (1991), who consider that these Permian magmatic rocks were formed on an active continental margin or in an island arc tectonic setting related to the subduction of the Paleo-Asian oceanic plate under the Sino-Korean and Siberian paleoplates. The other (Shao, 1991; Tang, 1992) argue that these Permian bi-modal magmatic rocks are products of magmatic activity in an intra-continental extensional tectonic setting.

Geochemical data from the volcanic rocks of this region provide the possibility of discussing and resolving this issue. Major element analytical results of about 300 samples from Permian volcanic rocks of southeastern Inner Mongolia are plotted on Fig. 4. These data show that these volcanic rocks show a continuous evolution from basic to acid compositions, without any bi-modal features. Their relatively high Al_2O_3 and low MgO contents suggest that they were erupted on active continental margins. Therefore, it is evident that a model of subduction-related continental margins is a more likely tectonic setting for the formation of these Permian magmatic rocks (Li, 1985, 1986, 1998; Wang et al., 1991; Nie et al., 1994; Jia and Wu, 1995; Jiang et al., 1995b; Leng et al., 1996; Geng, 1998; Wang and Gong, 2000; Wang, 2001) than an extensional rift setting, either within a continent or within a post-collisional amalgamated land mass (Shao, 1991; Tang, 1992; Hong et al., 1995).

Magmatic rocks, in combination with ophiolites and associated continent-marginal sequences, suggest that during the Late Paleozoic an Andean active margin was located on the northern Sino-Korean paleoplate, to the south of the Kedanshan-Xingshuwa ophiolite belt (the Xar Moron river), and that a Cordillera-type active continental margin existed to the north of this belt.

Further, it is evident from the above descriptions and discussions of the ophiolite belts, the continent-marginal rock sequences, the Permian sedimentary sequences, the magmatic zoning and chemistry of the Permian volcanics, and the evolution of paleo-biogeography that the Permian marine basin in southeastern Inner Mongolia and central Jilin Province was a residual basin of the Paleo-Asian Ocean and which did not close until the late Permian.

4. Position and timing of the suture of the Paleo-Asian ocean

The position and timing of the closure of the suture of the Paleo-Asian Ocean are other hotly-debated issues. Various suggestions on the position of the suture have been put forward

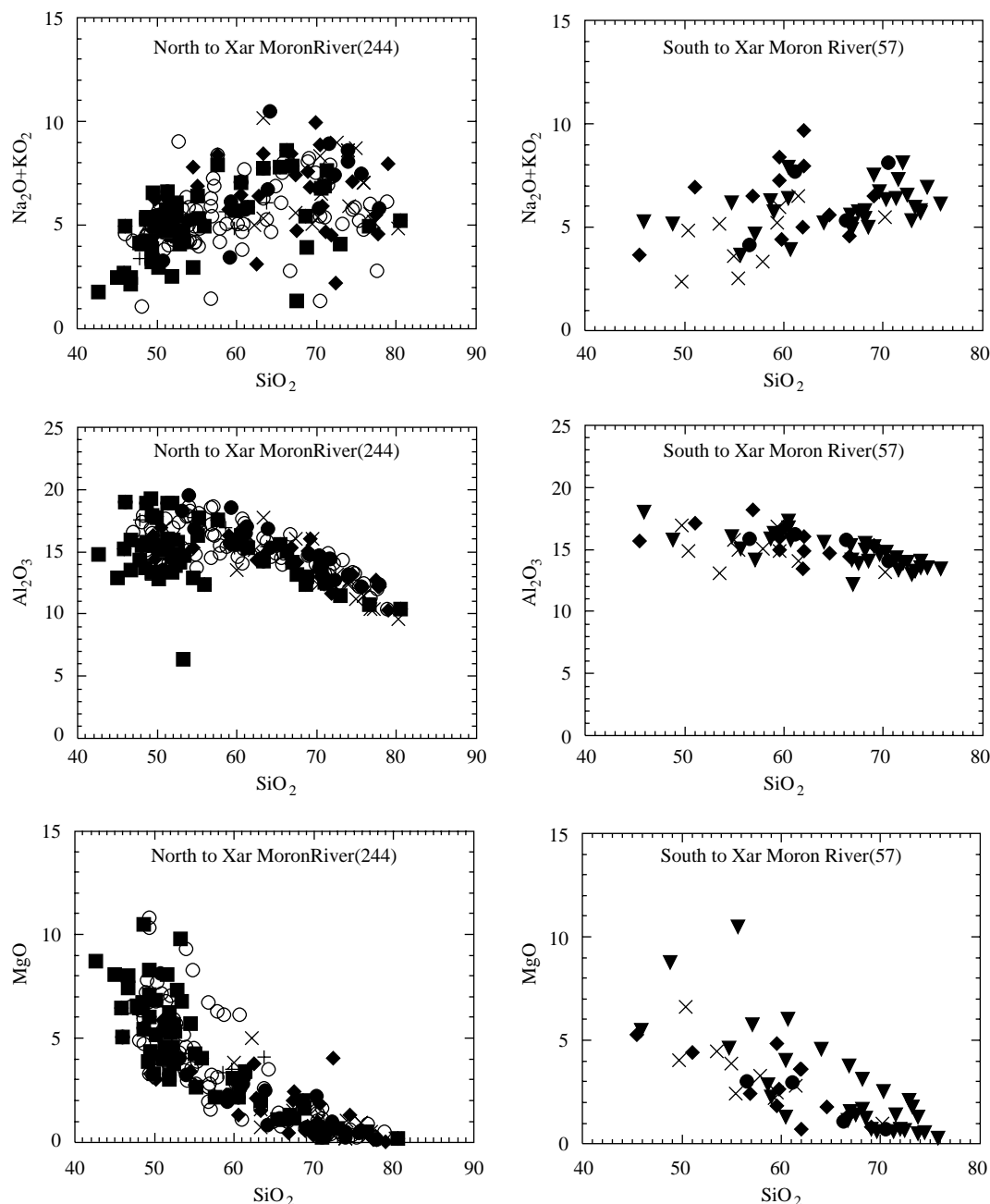


Fig. 4. Diagrams of major elements of Permian volcanic rocks from eastern Inner Mongolia, showing occurrence of continuous basic, intermediate, and acid volcanic rocks in the area. Data from \blacklozenge Li (1985), \circ Shao (1991), \bullet Wang et al. (1991), \blacksquare Tang (1992), \blacktriangledown Nie et al. (1993), \times Su et al. (2000) and $+$ Wang (2001).

based on various types of geological data and interpretation (Liu and Shan, 1979; Khain, 1979; Chi et al., 1981; Cao et al., 1986; Guo, 1986; Zhang and Tang, 1989; Tang, 1990, 1992; Shao, 1991; Ren et al., 1999; Nozaka and Liu, 2002) (Fig. 5), but none appears to account for all the geological data. There is little doubt that the Suolunshan ophiolites represent the position of the suture of the eastern Paleo-Asian Ocean and the age of suturing is probably Middle Permian. However, various interpretations for the eastward extension of this suture have been proposed in the literature. For example, Li (1980); Li et al. (1982), based on a regional synthetical analysis of then available geological and palaeontological data, suggested that

the suture extends from Suolunshan, eastwards along the Xar Moron river, central Jilin Province, to Tumen in eastern Jilin Province and was formed in the Permian. On the contrary, Cao et al. (1986); Guo (1986); Shao (1991); Nozaka and Liu (2002) considered that the Hegenshan ophiolite belt is the eastward extension of the Suolunshan suture in eastern Inner Mongolia. Cao et al. (1986) supposed that its further eastward extension turns into a NE direction through Heihe.

On the other hand, Wang (1986); Wang and Liu (1986), Li (1987a, 1998), Zhang and Tang (1989), Tang (1990, 1992), Wang et al. (1991); Sengör and Natal'in (1996); Xu et al. (1996); Xu and Chen (1997); Xiao et al. (2003) believe that the

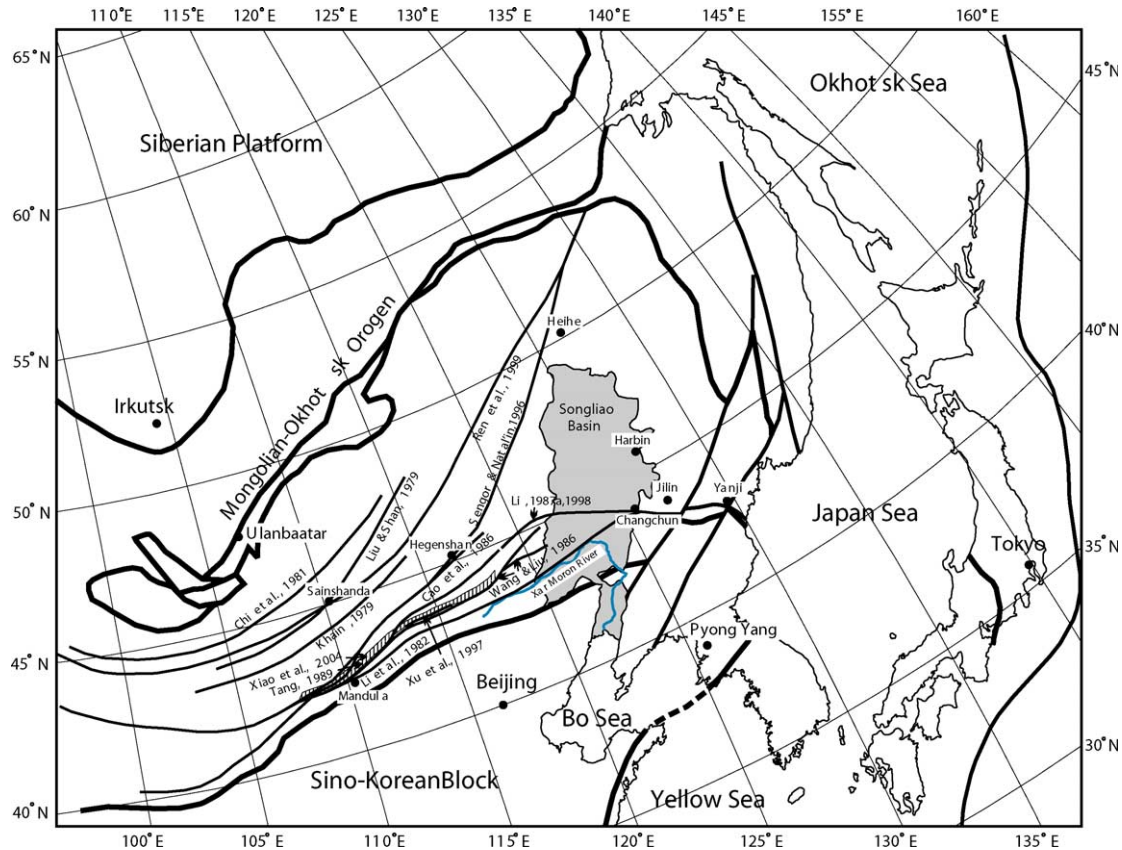


Fig. 5. Various opinions concerning the position of the eastern suture of the Paleo-Asian ocean proposed by different geologists. Details are given in the text.

suture extends from Suolunshan eastwards through the region between the Hegenshan ophiolites and Xar Moron river. Wang (1986); Wang and Liu (1986) and Li (1987a, 1998) suggested that further eastward extension of the suture goes through the central Jilin Province to the Yanji area, and that both sides of the suture were active continental margins with island-arc volcanic rocks and plutons. Li (1998) argued that the Hegenshan-Heihe ophiolite belt represents the suture between the Siberian paleoplate and Burean-Jiamusi Block based on geological and paleobiogeographical data. Xu (1995) summarized available data from geological surveys of Jilin Province and argued that the suture between the Siberian and Sino-Korean paleoplates goes through the central Jilin Province.

Sengör and Natal'in (1996) suggested that the suture extends northeastwards through the area between the Burean-Jiamusi and Ergun blocks, and named it the Solonker Suture. Xiao et al. (2003) proposed an 'accretionary wedge collision model' to explain the tectonic evolution of the eastern Paleo-Asian Ocean and considered that the accretionary wedges of the Siberian paleoplate and the Sino-Korean paleoplate collided along a suture, basically the same as that suggested by Wang et al. (1991); Sengör and Natal'in (1996). But it needs to be pointed out that the supposed accretionary wedges of the two paleoplates are volcanic arcs, with continental basement of various ages. Sengör and Natal'in's (1996) interpretation of the position of the suture is similar to that of Cao et al. (1986), in which the Burean-Jiamusi Block is considered to be part of the Sino-Korean paleoplate. This model ignores the

paleobiogeography and the Late Paleozoic magmatic activity in the central Jilin Province.

New data from recent geological surveys in the Mandula area east of Suolunshan in eastern Inner Mongolia (Su et al., 2000) and central and eastern Jilin Province (Xu, 1995; Zhang et al., 2000) show that the eastern Paleo-Asian Ocean was not completely closed until the Late Permian. Recently, some new data concerning structural deformation along the Xar Moron fault belt have been obtained by the author (2004, unpublished), including the recognition of Triassic post-collisional granite plutons, metamorphic complexes, and strike-slip deformation, implying that the Kedanshan-Xingshuwa ophiolite belt is probably part of the suture between the Siberian and Sino-Korean paleoplates as suggested by Li (1980); Li et al. (1982).

The unconformity between the upper Devonian and underlying geological bodies in Sunid Zuoqi, which was considered to be the strongest evidence of plate collision before the late Devonian (Tang, 1992), is not observed in other areas of northeast China and adjacent regions. In contrast, in areas north of the Hegenshan ophiolite belt, continuous marine Devonian through to Lower Carboniferous strata are exposed (BGMRNMR, 1991; Du et al., 1988), indicating that the unconformity probably records only a local transgressive event.

To sum up, the author is inclined to the interpretation that the suture which extends from the Suolunshan eastwards through the Mandula area, on the northern bank of the Xar

Moron river, from central Jilin Province to the Yanji area, marks the final collision zone between the two active continental margins of the Siberian and Sino-Korean paleo-plates, and that the final closing of the sea basin took place in the Late Permian. This view is based on various factors such as spatial and temporal distribution of continental marginal sequences and ophiolites and structural deformation; the proposed suture is also consistent with the boundary between the Permian biogeographical realms (see Shi, 2006).

5. Subduction of the Paleo-Pacific Oceanic Plate and its influence on the crustal evolution of Northeast China and adjacent regions

Remnants of the Paleo-Pacific Ocean are exposed in the Mongolian-Okhotsk orogens, the Wandashan of northeast China, Central Sikhote-Alin and the Sakhalin islands of eastern Russia, and Japan (Zonenshain et al., 1990; Kang et al., 1990; Zhang et al., 1997) (Fig. 3). Current explanations of the tectonic evolution of the Khangai-Khantey ocean or Paleo-Pacific Ocean, precursor of the Mongolian-Okhotsk orogens, are that the contraction and closure of the ocean is the result of the northward subduction of the oceanic lithosphere plate under the Siberian Plate, and that the Ergun-Central Mongolian margins of the ocean were passive margins, similar to those of the Atlantic Ocean (Zonenshain et al., 1990; Parfenov et al., 1995; Zorin, 1999). As seen in the Indian craton since the collision of India with Eurasia no magmatism or deformation occurs in the downgoing plate, only sedimentation in a foreland basin. If this model is correct, no magmatism or deformation would be expected in northeast China or adjacent regions during the Mesozoic, following the closure of the ocean. But in some publications, the long-distance effect of the collisional orogeny of the Mongolian-Okhotsk orogens is often considered as being a possible dynamic mechanism for Mesozoic crustal shortening and magmatic activity in northeast China (He et al., 1998; Davis et al., 1998; Wang et al., 2002a,b; Meng, 2003). This interesting and unresolved issue requires some discussion here.

Recently Sorokin et al. (2002) proposed that some fragments of Devonian-Permian active continental margins occur in the upper Heilongjiang (Amur) regions south of the Mongolian-Okhotsk Belt. Likewise, Zhang et al., (2003a,b) and Li et al. (2004a) have also reported the occurrence of Permian and Middle Jurassic granitoids in northernmost Heilongjiang Province of China, based on isotopic dating data. SHRIMP dating of zircons from the granitoids and metamorphic rocks in the upper Heilongjiang regions on both sides of the boundary between China and Russia (Li, 2004a, unpublished data) shows that multi-stage magmatic activity occurred on the northern margin of the Ergun Block from the late Neoproterozoic through to the Jurassic, implying that a long-lived evolving active margin was developed on the northern Ergun Block related to the tectonic evolution of the Khangai-Khantey ocean.

Devonian-Permian calc-alkaline volcano-sedimentary sequences and granitoids are exposed in the northern segment

of the Changbaishan Mountains in northeastern China and on the eastern slope of the Bureyan mountains in Russia (Li et al., 1999a,b), constituting a Late Paleozoic active continental margin, bordering the eastern Bureya-Jiamusi Block.

It should be pointed out that available geological data indicate an Ordovician collision of the Tuva, Central Mongolian and Ergun blocks with the Siberian Platform in turn, leading to the isolation of the Paleo-Pacific Ocean from the Paleo-Asian Ocean. Therefore, both sides of the Mongolian-Okhotsk orogen and the eastern Bureya-Jiamusi Block were different segments of the continental margin of the Siberian paleo-plate from the Silurian through to the Jurassic, probably similar to the western American margin of the Pacific since the Mesozoic.

The above analysis leads to the interpretation that the subduction of the Paleo-Pacific Oceanic Plate under the Ergun Block and the Bureya-Jiamusi Block began probably at least in the beginning of the Devonian and lasted to the Cretaceous. In this case the crustal evolution of northeast China and adjacent regions north of the suture between the Siberian and the Sino-Korean paleo-plates was associated with the subduction of the Paleo-Pacific Ocean in that time. The Triassic and Jurassic magmatic activity observed in eastern Altay (Zhang et al., 1994; Chen et al., 1999; Wang et al., 2002a,b), eastern Tianshan (H.Q. Li, 2004a, personal communications) and Beishan Mountains (Nie et al., 2002; Jiang et al., 2003) in northwest China also probably originated from the subduction of the Paleo-Pacific Ocean, similar to those in the eastern Asian continent since the Jurassic.

6. Preliminary reconstruction of Permian ocean-continent framework and the tectonic evolution of Northeast China and adjacent regions

The above discussion shows that during the Paleozoic, the evolving Paleo-Asian and the Paleo-Pacific oceans separated the Siberian Platform and Sino-Korean Block. By the Early Permian, based on the available geological data, the Siberian paleo-plate had amalgamated with the European, Kazakhstan, Tarim and Karakum blocks together with some other smaller massifs in northeast China and adjacent regions, to form a major continent. At this time, the Sino-Korean Block was surrounded by the Paleo-Tethyan, Paleo-Asian and Paleo-Pacific oceans (Fig. 6). The Paleo-Tethys was moving northwards and being subducted under the Karakum-Tarim and the Sino-Korean paleo-plates, the Paleo-Asian ocean was being subducted under the southern margin of the Siberian paleo-plate, and also under the northern margin of the Sino-Korean paleo-plate, the Paleo-Pacific Oceanic Plate was being subducted under the Siberian paleo-plate, but it is not clear if there was a subduction zone along the Sino-Korean margin facing the Paleo-Pacific ocean.

Available Early Permian paleomagnetic data show that the Siberian paleo-plate was located in high palaeolatitudes (about 60°N) of the northern hemisphere (Smethurst et al., 1998), the Sino-Korean paleo-plate in lower paleolatitudes (about 15°N on average) (McElhinny et al., 1981; Lin et al., 1985, 1998),

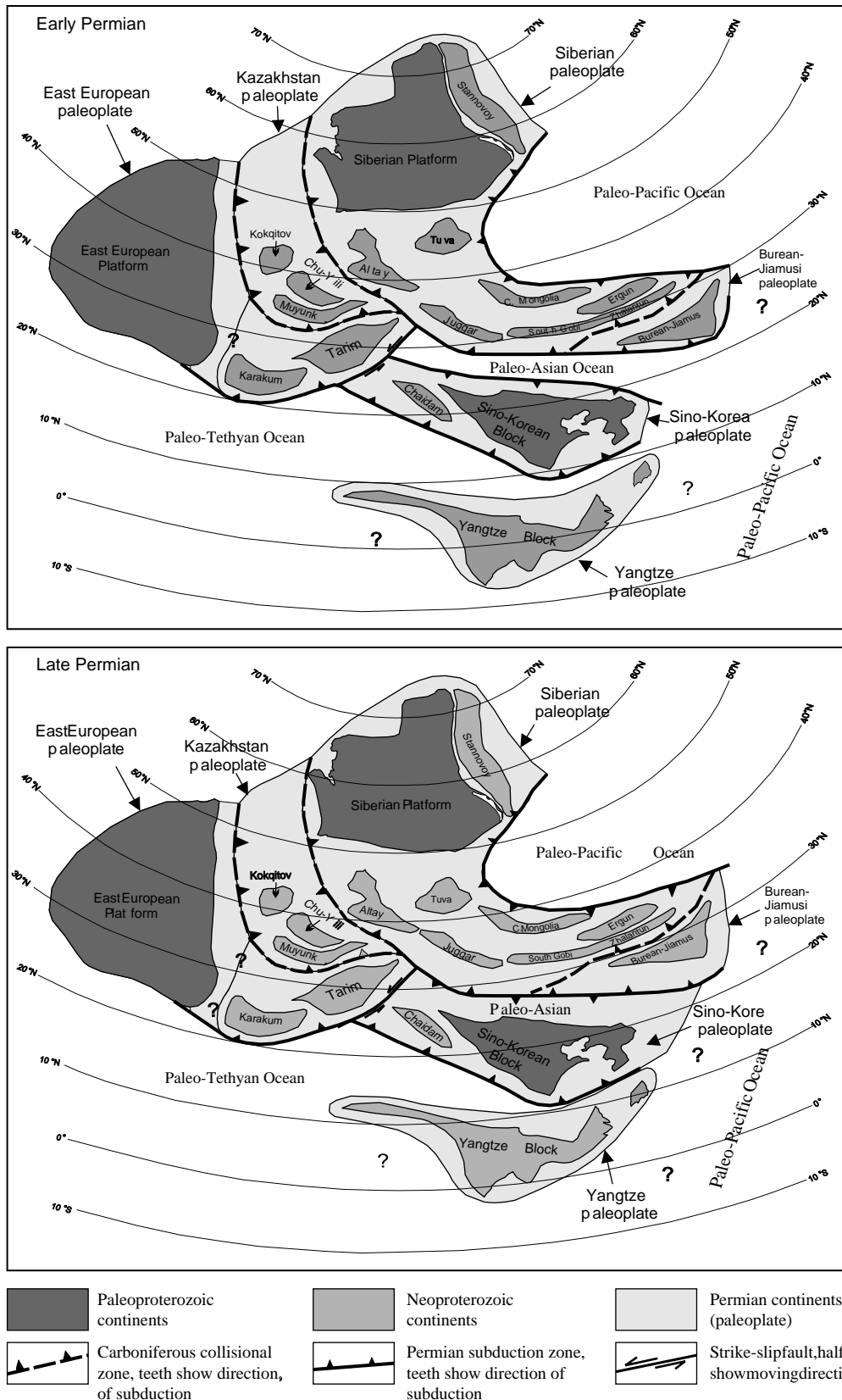


Fig. 6. Palinspastic reconstruction of Permian ocean-continent framework of Northeast China and adjacent regions. Considering crustal shortening and superposition along the collisional belts, larger areas of ancient continents are postulated in the map. Interrogation marks on the map show areas where the Early Permian tectonic setting is not clear. It is noteworthy that the size of paleoplate is different from that of blocks or platform, for example, the Siberian platform was much smaller than the Permian Siberian paleoplate.

the Tarim Block in mid-latitudes, about 25°N (Bai et al., 1987; Li et al., 1999a,b), and some blocks in northeast China and adjacent regions were also at mid-latitudes (about 20°N) (Pruner, 1992; Yang et al., 1998a,b; Kravichinsky et al., 2002). Similarly, the reconstruction of Permian paleobiogeography implies that the Sino-Korean paleoplate was located in warm to warm temperate zones of the northern Paleoequatorial Realm, and the Siberian paleoplate in the colder regions of the Boreal Realm during the Permian (Shi and Grunt, 2000).

Therefore, in view of the combined paleomagnetic, geological, and paleobiogeographical data with the kinematics of major faults (Yang et al., 2001; Zhang et al., 2001; Li et al., 2004b), the Permian ocean-continent framework of northeast China and adjacent regions may be palinspastically reconstructed as shown in Fig. 6. The geodynamic setting of East Asia during the Permian was mainly influenced by both the contraction of the Paleo-Asian Ocean and the subduction of the Paleo-Pacific Ocean.

At the beginning of the Early Permian, the Paleo-Asian Ocean had evolved into a very narrow basin due to continuing subduction of the oceanic plate under both its margins. A faunal admixture of Tethyan with Arctic (Boreal) species emerged, following the evolution of the ocean into an intercontinental remnant marine basin in the Middle Permian. A collisional orogeny in the eastern Paleo-Asian orogens probably took place following the closure of the Paleo-Asian Ocean at the latest Permian. The above synthesis reveals that the effect of the subduction of the Paleo-Pacific Oceanic Plate on the crustal evolution of northeast China and adjacent regions probably began in the Devonian and was limited to areas north of the suture of the eastern Paleo-Asian Ocean in the Late Paleozoic.

7. Conclusions

The spatial and temporal distribution of ophiolites, Permian sedimentary sequences and magmatic zonal patterns and paleobiogeography, reveal that the Permian marine basin in the eastern Paleo-Asian orogen of northeast China was a residual remnant of the Paleo-Asian Ocean. Regional geology, rock assemblages and geochemistry imply that Permian magmatic activity of southeastern Inner Mongolia occurred in an active continental margin tectonic setting (an Andean continental margin) on the northern part of the Sino-Korean paleoplate, while the southern margin of the Siberian Paleoplate was a Cordilleran continental margin. These two active continental margins collided in the Late Permian along a suture line which today extends from Suolunshan eastwards through the Mandala area, along the northern bank of the Xar Moron river, central Jilin Province to the Yanji area of the eastern Jilin Province.

Subduction of the Paleo-Pacific Ocean under the Siberian paleoplate in the north, and northeast China and adjacent regions to the south, began in the Devonian in view of geological and geochronological data. These subductions had an important influence on the Permian crustal evolution of northeast China and adjacent regions.

Thus, it is clear that the geological processes in northeast China and adjacent regions during the Permian were associated both with contraction and final closure of the Paleo-Asian Ocean and the ongoing subduction of the Paleo-Pacific Ocean. The former was related to the amalgamation of the Eurasian Continent, while the latter was associated with the accretion and final formation of the East Asian Continent. This conclusion reinforces the view that the Paleo-Pacific Ocean was different from the Pacific Ocean in its tectonic framework and geodynamical regime, and that the Permian tectonic evolution of East Asia was related to the evolution of both the Paleo-Asian and the Paleo-Pacific Oceans. However, the timing and processes of the transition in geodynamical regime from the Paleo-Asian Ocean to the Pacific Ocean since the Permian remains a question to be resolved.

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