Science in China Series D: Earth Sciences

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Discovery of a Late Permian Angara-Cathaysia mixed flora from Acheng of Heilongjiang, China, with discussions on the closure of the Paleoasian Ocean

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This work documents a new flora from the Upper Permian Hongshan Formation of Acheng County, Heilongjiang Province, Northwest China. The flora consists of 20 species: *Paracalamites* sp., *Pecopteris tangwangheensis* Huang, *Callipteris obese* Huang, *Callipteris shenshuensis* Huang, *C. tangwangheensis* Huang, *C. heilongjiangensis* Huang, *C. zeilleri* Zalessky, *C.* sp., *Comia yichunensis* Huang, *C. tenueaxis* Huang, *Iniopteris sibirica* Zalessky, *Supaia teiliensis* Huang, *Compsopteris tchirkovae* Zalessky, *C.* cf. *adzvensis* Zalessky, *Nilssonia* sp. 1, *Nil.* sp. 2, *Taeniopteris* cf. *densissima* Halle, *T.* cf. *nystraemii* Halle, *T.* sp. and *Noeggerathiopsis derzavinii* Neub. It is dominated by Angara species but mixed with some typical Cathaysian elements. The age of the flora is assigned to late of the Late Permian according to the stratigraphic ranges of the known species and the comparisons of it with the similar floras. The new discovery indicates that the final collision between the North China Plate and Siberian Plate occurred in Late Permian along the Xar Moron River-Changchun-Yanji sutured zone, and the Paleoasian Ocean was finally closed at the end of the Permian.

Late Permian, mixed Angara-Cathaysia flora, Paleoasian Ocean, plate collision, Heilongjiang Province of China

China is the only country in the world that possesses all the four major biogeographic realms namely the Eurameria, Cathaysia, Angara and Gandwana, during the Carboniferous-Permian period[1]. The tropic-subtropic Cathaysia floras and the temperate Angara floras occupy almost all China territory except south Tibet of SW China where the Gandwanan floras present and the Tarim Basin in NW China where the Eurameria floras occur. However, as Angara floras are chiefly distributed in the north boundary areas of China, including Xinjiang, Gansu, Ningxia, Inner Mongolia, northern Jilin and Heilongjiang, which belong mostly to the Tianshan-Hinggan orogenic belt. Because the Tianshan-Hinggan orogenic belt consists of very complicated tectonic and geographic units and has poor accessibility, studies on the Angara floras are still preliminary[2−15] as compared with the Cathaysian floras.

As an important geological event during the Middle-Late Permian, the mixture between the Cathaysian and the Angara floras along the boundary between the two phytogeographic provinces has been studied for decades[16−24], but the main features and the developmental history of the mixed floras remain poorly understood because only a few fossil sites are known.

The closure of the Paleoasian Ocean (a vast ocean situated between the Siberian, North China and Tarim plates during the Late Paleozoic) is an important geological event in the earth history. The developmental history of the Paleoasian Ocean has become an active subject of academic research since the 1980s. Some re-

Received April 5, 2009; accepted August 24, 2009
doi: 10.1007/s11430-009-0200-2
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Support of the National Program on Key Basic Research Project (Grant No. 2006CB701400)

Citation: Deng S H, Wan C B, Yang J G. Discovery of a Late Permian Angara-Cathaysia mixed flora from Acheng of Heilongjiang, China, with discussions on the closure of the Paleoasian Ocean. Sci China Ser D-Earth Sci, 2009, 52(11): 1746-1755, doi: 10.1007/s11430-009-0200-2

markable progresses have been made in tectonic geology, petrology, paleontology, biogeography, and tectonopaleogeography during the past decades, but the time and position of the final collision between the Siberian Plate and North China Plate are still two basic problems that remain to be solved[25−56]. Some authors even believe that no ocean but only mountains existed between the Cathaysian and Angara floristic provinces in the Late Paleozoic[57].

Paleontological and paleobigeographic data have become particularly important for the reconstruction of the tectonopaleogeography, and plant fossils play a key role in the study of the evolution of the paleo-continents. Here we report a new finding of an Angara-Cathaysia mixed flora from Acheng County of Heilongjiang Province, Northeast China that reveals the relationship between the Siberian and North China Plates and the final closure of the Paleoasian Ocean.

1 Stratigraphy and fossil site

The plant fossils studied here were collected from the Upper Permian Hongshan Formation in Hujiacun Village, Jiaojiezhen Town, Acheng County, Heilongjiang Province, NE China (Figure 1). The Hongshan Formation was established at the Hongshan section, Yichun City, Heilongjiang Province. At the stratotype section, the Hongshan Formation consists chiefly of grayish white coarse sandstone, fine sandstone intercalated with black slate and carbonaceous slate at the base; alternated by grey pebbly coarse sandstone, fine sand stone, siltstone and slate in the middle part, and grayish dark and light grey fine sandstone, silty slate intercalated with pebbly coarse sandstone in the upper part[58]. It is rich in plant fossils[2,59].

Similar to the stratotype section, the Hongshan Formation at the Hujiacun section is well exposed and composed mainly of pebbly coarse sandstone, fine sandstone, siltstone, silty slate, and carbonaceous slate, and is rich in plant fossils as well. The plant fossils are contained chiefly in the silty and carbonaceous slates.

2 Characteristics of the flora

The present flora consists of 20 species: *Paracalamites* sp., *Pecopteris tangwangheensis* Huang, *Callipteris obese* Huang, *Callipteris shenshuensis* Huang, *C. tangwangheensis* Huang, *C. heilongjiangensis* Huang, *C. zeilleri* Zalessky, *C.* sp., *Comia yichunensis* Huang, *C. tenueaxis* Huang, *Iniopteris sibirica* Zalessky, *Supaia teiliensis* Huang, *Compsopteris tchirkovae* Zalessky, *C.* cf. *adzvensis* Zalessky, *Nilssonia* sp. 1, *Nil.* sp. 2, *Taeniopteris* cf. *densissima* Halle, *T.* cf. *nystraemii* Halle, *T.* sp. and *Noeggerathiopsis derzavinii* Neub. (Figure 2). It is dominated by fern-like plants, and associated with some Sphenophyllales, Cordaitopsida, and Cycadopsida. Among them, *Paracalamites* of Sphenophyllales, *Comia*, *Supaia* and *Iniopteris* of seed fern, and *Noeggerathiopsis* of Cordaitopsida are typical or common Angara elements, which were frequently found in the central area of the Angara floristic province, such as the Kuznetsk Basin of Russia, northern Xinjiang of NW China and the Da Hinggan and Xiao Hinggan Mountains of NE China. They are absent from the Cathaysian and Euramerian Floristic Provinces. *Callipteris*, one of the most abundant seed ferns in the Angara and Eurame-

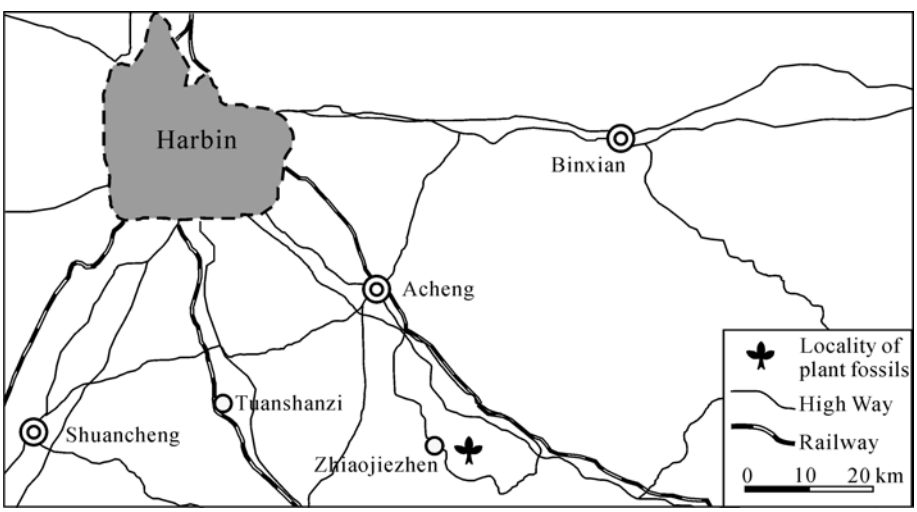

Figure 1 Sketch map showing the location of fossil plants.

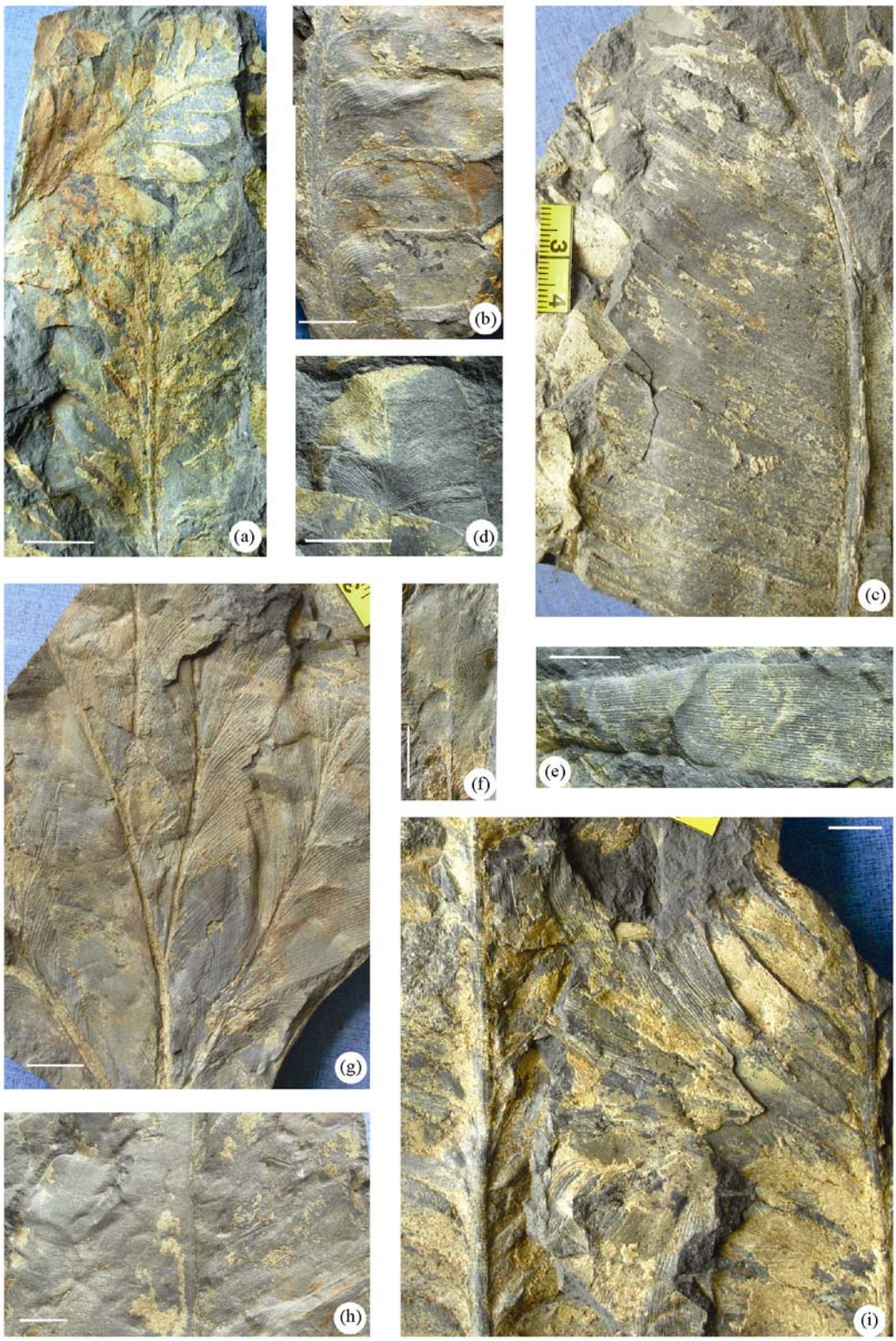

Figure 2 Some of the plant fossils from the Hongshan Formation. Scale=1 cm. (a) *Callipteris zeilleri* Zalessky, specimen number: HJT-02-93; (b) *Compsopteris tchirkovae* Zalessky, specimen number: HJT-02-19; (c) *Taeniopteris* cf. *densissima* Halle, specimen number: HJT-02-51; (d) *Comia yichunensis* Huang, specimen number: HJT-02-65; (e) *Noeggerathiopsis derzavinii* Neub., specimen number: HJT-02-44; (f) *Compsopteris* cf. *adzvensis* Zalessky, specimen number: HJT-02-26; (g) *Comia tenueaxis* Huang, specimen number: HJT-02-5; (h) *Taeniopteris* cf. *nystraemii* Halle, specimen number: HJT-02-17; (i) *Callipteris heilongjiangensis* Huang, specimen number: HJT-02-1.

rian floras is represented by five species in the present flora, among which *C. zeilleri* is one of the most important species of the Russian Angara floras and the others are possibly endemic species that have only been reported in the Da Hinggan and Xiao Hinggan Mountains of Northeast China so far[2,5,6]. Therefore, the present flora is dominated by Angara elements and is of undoubted Angara features.

However, it is noticeable that there are some Cathaysian members in the species list of the present flora as well, which include *Taeniopteris* cf. *densissima*, *T.* cf. *nystraemii*, and *T.* sp. *Taeniopteris* has been proved an important genus of the Cathaysian flora[60,61], and species *Taeniopteris densissima* and *T. nystraemii* are widely distributed in the Permian of North China. The studied specimens identified as *Taeniopteris* cf. *densissima* and *T.* cf. *nystraemii* are very close to two North China species. Although the Cathaysian elements make up only a small percentage of the present flora, the specimens of these species occur abundantly in the sediments, showing that they flourished in the flora. Consequently, the present flora is an Angara type flora mixed with some Cathaysian elements.

3 The age of the flora

The stratigraphic ranges of the main species of the present flora indicate a Late Permian age. *Comia* had only been recorded from the Upper Permian of Russia and China. *Iniopteris sibirica*, a very common species of the Russian Late Permian Kuznetsk flora, was also reported from the Upper Permian of Northwest China and Northeast China[2,14], without any record below the Upper Permian. The first appearance of *Callipteris zeilleri* was earlier than the Late Permian, but it flourished in the Late Permian in the Russian Kuznetsk Basin and Euramerian Province. In China, *C. zeilleri* was previously reported from the Upper Permian of Tianshan-Hinggan region, such as the uppermost of the Permian Biyoulebaoguzi Formation in Tarim Basin[62], the Xiacangfanggou Group of Junggar and Turpan basins[14], the Upper Permian Linxi and Hongshan formations of Northeast China[2,19,59]. Additionally, two species of *Compsopteris* have previously been recorded only in the Upper Permian[2,63]. *Noeggerathiopsis derzavinii* was originally recorded in the Lower Permian Upper Balakhonckya Formation of Siberia, Russia, but had been reported in much higher horizons in China, such as the Upper Permian Sunan Formation of Sunan County of Gansu Province[64], the Linxi Formation of the central Da Hinggan region[5], and the Hongshan Formation of the Xiao Hinggan region[2]. Thus, it seems a rather long-ranging species. As mentioned above, the other known species, including *Supaia teiliensis*, *Comia yichunensis*, *Callipteris obese*, *C. shenshuensis*, and *C. tangwangheensis* are possibly endemic elements to Northeast China, of which all the previously records are restricted in the Upper Permian[2,5,7,8,19,59].

The present flora is comparable well with several Upper Permian floras in Tianshan-Hinggan area.

The Linxi flora in the Da Hinggan region consists of more than 60 species, and is characteristic by typical Angara genera, including *Comia*, *Supaia*, *Iniopteris*, *Callipteris*, and *Noeggerathiopsis*, and also associated with a few typical Cathaysia elements as well[5,8]. The Linxi Formation is of a Late Permian age because it is over the beds containing Middle Permian marine animal fossils.

Another important flora similar to the present one is the Late Permian Hongshan flora of Yichun, Heilongjiang Province. It consists of about 60 species of 25 genera, and dominated by Angara species, with a few Cathaysian elements as well[2,19,59]. It has been referred to Late Permian. The common species between the Hongshan and the present floras include *Callipteris tangwangheensis*, *C. zeilleri*, *Comia yichunensis*, *Iniopteris sibirica*, and *Supaia teiliensis*, showing their close relationship in composition and age.

The Angara floras in northern Xinjiang, Northwest China have been studied for decades and summarized as *Callipteris* Flora[9−13], which can be further divided into three assemblages in ascending order as: *Callipteris-Comia-Iniopteris*, *Zamiopteris-Viatscheslavia*, and *Callipteris-Schizoneura*[14]. The present flora is correlated well with the *Callipteris-Comia-Iniopteris* assemblage, which is assigned to the Late Permian[14].

In summary, both the stratigraphic ranges of the known species and the correlations with the similar floras indicate that the present flora is undoubtedly the Late Permian, and most possibly late part of the Late Permian by considering the stratigraphic position.

4 Discussion on the Paleoasian Ocean

The final closure of the Paleoasian Ocean is an important geological event in the earth history, which is re-

lated to the collision between the Siberian and North China plates and the formation of the Euroasian continent. The evidence for this geological event is recorded in the Tianshan-Hinggan orogenic belt in the north of China.

It is commonly accepted that there existed many small blocks (called the Junggar block group) in the west part of the Paleoasian Ocean during the Late Paleozoic. This block group has an affinity with the Siberian tectonic domain, in which the Angara floras were distributed. These small blocks successively attached to the Siberian Plate within the Carboniferous, and became parts of the latter[65]. In the southern area of the Tianshan Mountains there existed the Tarim Plate, on which the Euramerian floras were developed. The collision between the Tarim Plate and the Kazakstan Plate happened during the Devonian to Early Carboniferous[66], and resulted in the Angara plants invading into the Tarim Plate from the Siberian Plate (including the Junggar block group) in the early part of the Middle Permian and totally replacing the Euramerian floras in the Late Permian[14,20]. This demonstrated that the land-land collision between the Siberian and Tarim plates started before the Middle Permian. Hence, in the west part of China the Paleoasian Ocean possibly disappeared in the Middle Permian.

However, in the eastern part of the Paleoasian Ocean, i.e., the middle-east Tianshan-Hinggan orogenic belt, the position and time of the Paleoasian Ocean's closure are two controversial questions due to the structurally complexity, although many efforts have been concentrated on these two issues in the past decades.

4.1 The position of the final collision and suturing between the Siberian and North China plates

The position of the final collision and suturing of the Siberian and North China plates is one of the hotly- debated academic issues. Various suggestions have been proposed based on the lithologic and paleogeographic and tectonic studies of the Tianshan-Hinggan orogenic belt[67], of which three major ones are: Mongolian-Okhotsk[39,48], Hegenshan-Renjiang River-Heilongjiang River[32,37,40,47,53], and Xar Moron River-Changchun-Yanji[30,34,36,44,68].

An acceptable conclusion drawn in the studies during the past decades is that in the eastern part of the Paleoasian Ocean, i.e., between the Siberian and North China plates, there scattered many medium-small blocks, such as the Argun-Hinggan, Xilinhot, Jiamusi, Songnen, and Xingkai blocks[69]. These blocks moved gradually and collided successively to each others during the Paleozoic and therefore finally resulted in a large "North Inter-Block" at the end of the Carboniferous[70]. Therefore, there existed three major blocks in eastern part of the Paleoasian Ocean, which are Siberian Plate, North Inter-Block, and North China Plate in southward order.

The North Inter-Block, belonging to the Siberian tectonic domain, is of Siberian features, which is supported by paleontologic data. The faunas and floras in the North Inter-Block, the same as those occurring in the Siberian Plate, belong to the north temperate biogeographic province[68,71]. In contrast, the faunas and floras in the North China Plate belong to tropic-subtropic biogeographic province. Therefore, the sutured zone between the North Inter-Block and the North China lates, i.e., the Xar Moron River-Changchun-Yanji sutured zone, is the boundary between the two paleobiogeographic provinces (Cathaysian and Angaran) and the boundary between the tropic-subtropic and the temperate climatic zones during the Carboniferous and Permian. The biogeographic difference between the North Inter-Block and the North China Plate is much greater than that between the North Inter-Block and the Siberian Plate.

The discovery of the Middle Permian radiolarians from the ophiolite of the Xar Moron River suturing zone demonstrates that it is the youngest ophiolite between the Siberian and the North China plates. In other words, this suture zone should be the position of the final closure of the Paleoasian Ocean as well as the final suture of the two plates[36,42].

Additionally, Li[54] demonstrated that the Bureja-Jiamushi block (the major part of the North Inter-Block) is sutured with the Siberian Plate during the Devonian-Carboniferous, based on lithologic, stratigraphic, and tectonic information, which means that the North Inter-Block was part of the Siberian Plate before the Permian.

Therefore, the Xar Moron river-Changchun-Yanji suturing zone should be the position of the finial collision between the Siberian and the North China Plates, namely the position of the finial closure of the Paleoasian Ocean.

4.2 The time of the final closure of the Paleoasian Ocean

The timing of the final collision between the Siberian and

North China plates or the final disappearance of the Paleoasian Ocean is another hotly-debated subject. Various viewpoints on this subject have been put forward, including the end of the Early Paleozoic[34], Late Paleozoic[27,32,35,37,47,49], end Permian[26,29,41,42,45,46,50−52,56,70] and Early Mesozoic or even Early Cretaceous[31,38].

Paleobiogeographic data play an important role in reconstruction of the paleoplates, and land plant fossils are particularly useful for analysis of the relationship between paleo-continents.

Radiolarians, a kind of deep marine animals, have been found from the Middle Permian Zhesi Formation of Zhesi area of central Inner Mongolia and Xilinhot area of eastern Inner Mongolia[42], as well as from the Middle Permian sediments of Linxi area of the north bank of the Xar Moron River[36]. These radiolarian data demonstrated that the Paleoasian Ocean did not close until the Middle Permian. The Middle Permian strata in northeastern China are composed mainly of marine and no-marine-marine altered facies sediments, with limited terrestrial beds; on contrary, the Upper Permian strata consist of almost totally terrestrial formations. These also mean that marine water extensively exited during and before the Middle Permian and then the sea gradually contracted and finally disappeared in the Late Permian.

The North Inter-Block is geographically situated to the north of the Xar Moron River, and belonged to the north temperate climatic zone in the Middle Permian. There were cold-water marine faunas in the ocean and temperate floras on the land. Coral fauna are composed mostly of minitypes and monocases, such as *Lytvolasma*, *Tachylasma*, *Callophyllum*, *Lophophyllidium* and *Lohlocarinophyllum*; other cold-water animals included *Monodiexodina* of fusulinidea, *Spiriferella* and *Kochiproductus* of brachiopods, etc. However, these faunas were mixed with a few warm-water or possible warm-water elements, such as colonial coral *Wenzellophyllum* and Tethyan fusulinidea *Parafusulina*[21,24]. However, the floras on the land were of typical Angara features. For instance, the *Crassinervia-Neuropsis-Zamiopteris* Assemblage from the Middle Permian Tumenling Formation in Xiao Hinggan Mountains[2], the Daheshen Formation of Zhangguangcailing area and the Tatouhe Formation of Mishan and Laoyeling area are composed of typical Angara species, without any Cathaysian element.

In contrast, in the area to the south of the Xar Moron River, the marine faunas are dominated by warm-water types that are distributed in tropic and subtropic zones, including colonial corals and Tethyan fusulinidea. However, these marine faunas are mixed with a few cold-water species as well. The floras on the lands belong to the tropic-subtropic Cathaysia type. As an example, the flora from the Middle Permian Yujiabeigou Formation in Wengnieute Banner and Aohan Banner of Inner Mongolia, consisting of 48 species, is dominated by typical Cathaysia elements including *Lepidodendron*, *Tingia*, *Neuropteris*, *Lobatannularia*, *Fascipteris*, *Taeniopteris*, and *Gigantonoclea*[3,8], without any Angara species mixed.

Consequently, paleontologic and paleobiogeographic data strongly support the existence of an ocean (Paleoasian Ocean) between Siberian and North China plates till the Middle Permian. But the Siberia and North China plates were not very far away as indicated by some invaded marina animal species from each other during the Middle Permian.

The ecosystem in the Tianshan-Hinggan region started changing obviously after the Middle Permian. According to the systematic studies by Wang and Zhang[72], the cold-water brachiopod fauna in the North area to the Xar Moron River went extinct at the end of the Middle Permian. The first stage of extinction happened at the end of the Wordian Age (Middle Permian) due to temperature rising. This temperature rising was possibly related to the Siberian Plate's moving southward.

The immigration, intrusion, and mixture of the elements between the moderate Angara flora and the tropic-subtropic Cathaysia flora indicate that the Siberian Plate (including the North Inter-Block) was sutured with the North China Plate in the Middle Permian and final land-land collided in the Late Permian. These mixtures are presented in two ways. One is that the Angara elements intruded into the Cathaysia flora, and the other is the Cathaysia elements into the Angara flora. The former occurred in the western and northwestern Gansu of Northwest China, the south side area of the Xar Moron River-Changchun-Jilin sutured zone in Northeast China, and the central area of North China; while the latter happened in northern Xinjiang, Middle part of Inner Mongolia, and Jilin and Heilongjiang which are situated north to the Xar Moron River-Changchun-Jilin sutured zone (Table 1, Figure 3).

Table 1 The main elements that intruded into Angara or Cathaysia floras

Cathaysia Floristic Province		Angara Floristic Province	
Locality/formation/age	Angaran elements intruded	Locality/formation/age	Cathaysian elements intruded
Sunan of Gansu/Dahuanggou Fm.-Yaogou Fm./P_2^2-P_3^1	*Zamiopteris glossopteroides*, *Noeggerathiopsis*	Northern Xinjiang /Xiacangfanggou Group /P_3	*Taeniopteris densissima*, *T.* aff. *novinii*
Sunan of Gansu/Sunan Fm./P_3^2	*Callipteris bexellii*, *Pursongia lanceolata*, *Zamiopteris glossopteroides*, *Noeggerathiopsis derzavinii*, *Peltaspermum buevichae*, *P. multicostatum*, *Paracalamites tenuicostatus*	Yanji of Jiin/Jiefangcun Fm./P_3	*Acitheca* cf. *unifurcata*, *Schizoneura manchuriensis*, *Pecopteris latirenosa*, *P.* (*Asteratheca*) *orientalis*, *Taeniopteris* cf. *angustifolia*, *Taeniopteris* sp., etc.
Beishan of North Gansu /Hongquan Fm. and Fangkoushan Fm./P_3^2	*Zamiopteris glossopteroides*, *Paracalamites tenuicostatus*	Da Hinggan of Middle Inner Mongolia/Linxi Fm./P_3	*Pterophyllum eratum*, *Schizoneura manchuriensis*, *Pecopteris* cf. *lepidorachis*, *P.* cf. *orientalis*, *Taeniopteris* cf. *integra*, *Sphenopteris* cf. *grabaui*
South of Jilin /Kaishantun Fm./P_3	*Paracalamites manchuriensis*	Yicun of Heilongjiang /Hongshan Fm./P_3^2	*Pecopteris yabei*, *P.* cf. *cyathea*
Shanxi /Sunjiagou Fm./ P_3^2	*Tatarina* cf. *sinuosa*, *Phylladoderma* (*Aequistomia*) cf. *aequalis*, *Gaussia*? *shanxiensis*, *Zamiopteris glossopteroides*, *Noeggerathiopsis sinouralis*	Acheng of Heilongjiang /Hongshan Fm./P_3^2	*Nilssonia* sp., *Taeniopteris* cf. *densissima*, *T.* cf. *taiyuanensis*, *T.* cf. *nystraemii*

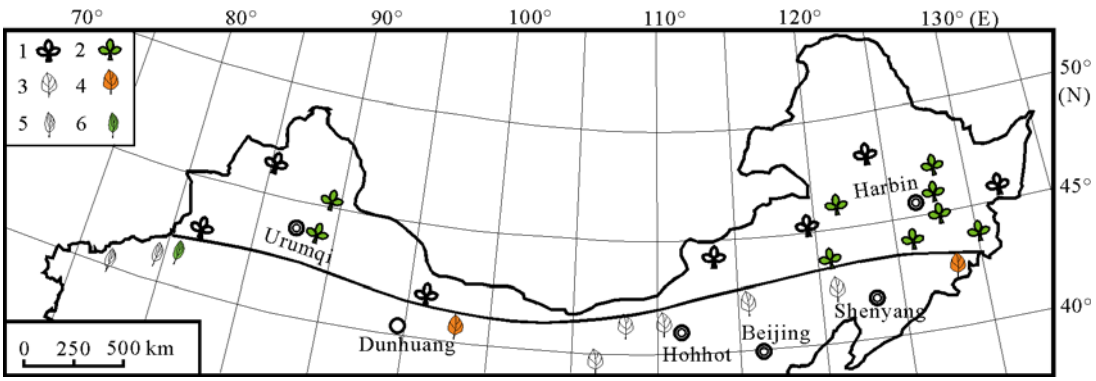

Figure 3 Distribution of the late Late Permian floras in the North of China. 1. Angara flora; 2. Angara flora mixed with Cathaysian species; 3. Cathaysian flora; 4. Cathaysian flora mixed with Angara species; 5. Euramerian flora; 6. Euramerian mixed with Angara species.

The Angara species started their intrusion into the Cathaysia flora in western Gansu in the Middle Permian. In Sunan County of Gansu, the Cathaysia floras from the Dahuanggou Formation (upper part of the Middle Permian) and the Yaogou Formation (lower part of Upper Permian) were mixed with a few Angara genera, such as *Zamiopteris* and *Noeggerathiopsis*[64], showing the influence of the Angara flora on the Cathaysia flora. But the floras from the Sunan Formation (upper part of the Upper Permian) and the similar age formations such as the Hongquan Formation and Fangkoushan Formation in Beishan Area (North Gansu and western Inner Mongolia) are composed of a considered number of the Angara elements. These imply that the Angara plants started their intrusion into the Cathaysia phytogeographic province in the Middle Permian in western Gansu and then resulted in Cathaysia-Angara mixed floras in the late part of the Late Permian (Table 1).

In Kaishantun of Jilin Province, which is situated in the south side of the Xar Moron River-Changchun-Jilin sutured zone, about 50 species of plant fossils have been discovered from the Upper Permian Kaishantun Formation[3,22,73]. The flora belongs to Cathaysian type because of the appearance of so many Cathaysia species, such as *Lobatannularia heianensis*, *Protoblechnum imaizumii*, *Taeniopteris crassicaulis*, *Nilssonia laciniata*, *Alethopteris* cf. *kaipingiana*. However, it was mixed with a few Angara or possible Angara elements, such as *Paracalamites manchuriensis*[18,22].

In Shanxi, the central area of the Cathaysian Floristic Province, no certain Angara species has been found from Shangshihezi Formation (upper Middle Permian-lower Upper Permian)[60], but there are some Angara elements including *Tatarina* cf. *sinuosa*, *Phylladoderma* (*Aequistomia*) cf. *aequalis*, *Gaussia*? *shanxiensis* in the overlying bed, the Sunjiagou Formation (the upper part of the Upper Permian)[60,61]. It implies that some Angara elements, although only a few, intruded into the center of

the Cathaysian Province during the end of the Permian.

To sum up, the intrusion of Angara species to the Cathaysian flora started in the west and then in the east area. The ratio of the intruders decreased with the distance from Xar Moron River-Changchun-Jilin sutured zone in Northeast China.

The intrusion of the Cathaysia elements into the Angara flora happened in the Late Permian as well. The main intruders includes *Pacopteris yabei*, *P.* cf. *cyathea*, *Schizoneura*, *Nilssonia* sp., *Taeniopteris* cf. *densissima*, *T.* cf. *taiyuanensis*, *T.* cf. *nystraemii*, etc. Here we cite some examples to illustrate this subject.

The flora from the Upper Permian Xiacangfanggou Group of North Xinjiang consisted of 50 species, characterized by the Angara types including *Comia*, *Iniopteris*, *Zamitopteris*, *Callipteris*, *Paracalamites* and *Noeggerathiopsis*, but a few Cathaysian floristic species such as *Taeniopteris densissima*, *T.* aff. *Norinii* and *T.* sp. were recorded as well[14].

In the north side of the Xar Moron River-Changchun-Jilin sutured zone, several mixed floras have been reported previously (Figure 3). A typical mixed flora is from the Jiefangcun Formation (called Jiefangcun flora) of Yanji, Jilin Province, close to the suture zone. The flora consists of about 60 species, of which typical Angara species occupy 38% and Cathaysian elements 27%[22,23]. Another mixed flora is the Linxi flora of central Inner Mongolia, quite far away from the suture zone. It consists of more than 60 species, which is dominated by the Angara plants such as *Comia*, *Supaia*, *Iniopteris*, *Callipteris* and *Noeggerathiopsis*[5,8], but mixed with only a few of Cathaysian elements *Taeniopteris*. Similarly, the Hongshan flora of Yicun, Heilongjiang is characterized by typical and important Angara members *Comia*, *Iniopteris*, *Zamitopteris*, *Tychtopteris*, *Petscheria*, *Glottophyllum* and *Lepeophyllum*, and the common Angara elements *Callipteris*, *Paracalamites*, *Noeggerathiopsis* and *Prynadaeophllum*, but mixed with a few Cathaysian plants such as *Pecopteris yabei* and *Taeniopteris* sp.[2,19,59].

As a new discovery, the present mixed flora from Acheng of Heilongjiang demonstrates again that the Angara flora was mixed with Cathaysian elements in the Late Permian.

Paleobotanic and paleophytogeographic data show the mixture of the north temperate Angara flora with the south tropic, subtropic Euramerian and Cathaysian floras in the Middle Permian in the western China and then eastward over time. This indicates that the land-land collision between the Siberian Plate (with the Junggar block group and the North Inter-Block) and the Tarim and North China plates happened in Middle Permian in west China and then in east China, and finally completed in end Permian, namely, the Paleoasian Ocean disappeared at end Permian.

5 Conclusions

(1) The flora from the Hongshan Formation of Acheng, Heilongjiang is dominated by the Angara species, but mixed with a few Cathaysian elements. The age of the flora is late Late Permian.

(2) The Siberian Plate (with the Junggar block group in the west and the North Inter-Block in the east) collided with the Tarim Plate and west part of the North China Plate in the Middle Permian, and then with the east part of the North China Plate along the Xar Moron River-Changchun-Yanji suturing zone in the Late Permian. The final land-land collision was completed toward the end of the Late Permian, and resulted in the final closure of the Paleoasian Ocean.

We thank Prof. Li Jinyi of Institute of Geology, Chinese Academy of Geological Sciences for his comments and useful suggestions on the draft and sending us his publications. We also thank Dr. Ding Qiuhong of Shenyang Institute of Geology and Minieral Resources for her help with literatures. The work started when the project "the stratigraphy, paleoenvironment and oil-gas perspective evaluation of the Carboniferous and Permian in the North of China", a key project funded by PetroChina, was carrying out.

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