Permian wood from Inner Mongolia, North China: with special reference to Palaeozoic climate change of North China Block

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ABSTRACT

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Three species of gymnosperm woods are discovered from the upper Shihhotse Formation of Inner Mongolia, North China, of which two are described as new, i.e., *Araucarioxylon neimongense* sp. nov. and *Araucarioxylon wndense* sp. nov., because of their high percentage of partly biseriate xylem rays. In accordance with Pant and Singh's (1987) suggestion on the taxonomy and classification of araucaroid fossil wood, the Palaeozoic gymnosperm fossil woods of araucaroid type in Cathaysian flora are re-evaluated. They are recombined within *Protophyllocladoxylon*, *Araucarioxylon*, *Zalesskioxylon*, *Chapmanoxylon* and *Cordaioxylon*. The presence or absence of growth rings and their vertical distribution pattern were closely related to the change of the palaeoclimatic condition resulted from the drifting of the North China Block from the tropical zone to the middle-high latitude zone throughout the late Palaeozoic.

Key-words—Fossil wood, Gymnosperm, Palaeoclimate, Cathaysian flora, North China.

उत्तरी चीन के अन्तर्वर्ती मंगोलिया से प्राप्त परमियन युगीन काष्ठ : उत्तरी चीन प्रखण्ड के पेलियोज़ोइकयुगीन जलवायुविक परिवर्तन के विशिष्ट सन्दर्भ में

वांग जुन

सारांश

उत्तरी चीन के अन्तर्वर्ती मंगोलिया के उपरि शिहोत्से शैलसमूह से अनावृतबीजी काष्ठ की तीन प्रजातियाँ खोजी गयी हैं, जिनमें *अराउकेरियॉक्सीलॉन नेइमांगेन्सी* नव प्रजाति तथा *अराउकेरियॉक्सीलॉन वुडेन्सी* नव प्रजाति नामक दो प्रजातियाँ उनमें आंशिक द्विपंक्तिक ज़ाइलम किरणों की उच्च प्रतिशतता के कारण नयी प्रजातियों के रूप में निर्धारित की गयी हैं. अराउकेरॉयड अश्मित काष्ठ के वर्गीकरण तथा वर्गिकी विज्ञान पर पंत एवं सिंह (1987) द्वारा दिए गए सुझावों के अनुरूप केथेसियाई वनस्पतिजात के अराउकेरॉयड प्ररूप के पेलियोज़ोइक अनावृतबीजी अश्मित काष्ठ का पुनर्मूल्यांकन किया गया है. इन्हें *प्रोटोफिल्लोक्लैडॉक्सीलॉन*, *अराउकेरियॉक्सीलॉन*, *जेलेक्सीऑक्सीलॉन*, *चैपमैनॉक्सीलॉन* तथा *कॉर्डऑक्सीलॉन* के अन्तर्गत पुनः संयुक्त किया गया है. वृक्ष वलयों की उपस्थिति अथवा अनुपस्थिति तथा उनका ऊर्ध्वाधर वितरण विन्यास उन पुराजलवायुविक स्थितियों में हुए परिवर्तनों से सहसम्बन्धित थे, जो सम्पूर्ण अन्तिम पेलियोज़ोइक कल्प के दौरान उत्तरी चीन प्रखण्ड के उष्णकटिबन्धीय मण्डल से मध्यम-उच्च अक्षांश मण्डल की ओर अपवाह के परिणामस्वरूप घटित हुए थे.

संकेत शब्द—अश्मित काष्ठ, अनावृतबीजी, पुराजलवायु, केथेसियाई वनस्पतिजात, उत्तरी चीन.

INTRODUCTION

THE locality of present fossil wood is situated about 106°18' E, 39°30' N, namely, Wuda, a small town in Alashanzuoqi of Inner Mongolia Autonomous Region, China (Fig. 1). Geographically it belongs to the northern part of Helan Mountain, and tectonically near the northwestern edge of North China Block (NCB, hereinafter). Therein the Upper Palaeozoic deposition, which supported the typical Cathaysian flora, is of north China type. Its stratigraphy is represented by a schematic generalized columnar section (Fig. 2).

The present studied specimens have been recorded from the Upper Shihhotse Formation.

After *Zalesskioxylon rhodeanum* comb. nov. was reported from the Permian of Hulustai (about 106°4' E, 39°15' N), Inner Mongolia (Sze, 1946), work on Permian fossil wood in this region has been scanty. Nevertheless, the widely scattered fossil wood specimens are gradually drawing attention of Chinese palaeobotanists. A good example is the work of Wang *et al.* (2000). The specimens treated here were collected during the geological investigation on regional stratigraphy and palaeontology in the 1980s. All the specimens are strongly silicified, and only secondary woods were preserved. Three (transverse, radial, tangential) sections were prepared and studied in transmitted light.

All slides studied are housed in Nanjing Institute of Geology and Palaeontology, Academia Sinica, with catalogue numbers HEW 165, 166, 169, 170.

DESCRIPTION OF FOSSIL WOOD

Genus—ARAUCARIOXYLON Kraus, 1870

Type species—ARAUCARIOXYLON CARBONACEUM (Witham) Kraus. 1870

ARAUCARIOXYLON NEIMONGENSE sp. nov.

(Pl. 1·1-6; Fig. 3)

Diagnosis—Growth rings poorly developed; tracheids large, tangential and radial diameters at least 80 μm; radial tracheid pits rounded, 1-5 seriate, usually 2-4 seriate; alternate in multiseriate arrangement, sometimes partly crowded in hexagonal form; most of xylem rays uniseriate, more than 1/3 partly biseriate, 1-35 cells high. Cross-field pits bordered, 1-7, mainly 3-5 in number.

Description—The new species is represented by a number of fragments of trunk, secondary xylem.

Transverse section—The tracheids are circular, elliptical or rectangular with rounded outline (Pl. 1·1,1a). When circular, diameter 25-40 μm, normally 35 μm; the thickness of tracheid walls 5-10 μm; ray cells trapezoidal, usually one spans 2-3 tracheids. Neither resin canal nor resin parenchyma is observed.

Radial section—Pits on the radial wall of the tracheids (Pl. 1·3-6) are bordered, 1-5 seriate, mostly 2-4 seriate. Uni- and biseriate pits are circular, not crowded, differing from pits of 3-5 seriate, which are distinctively crowded and partly in
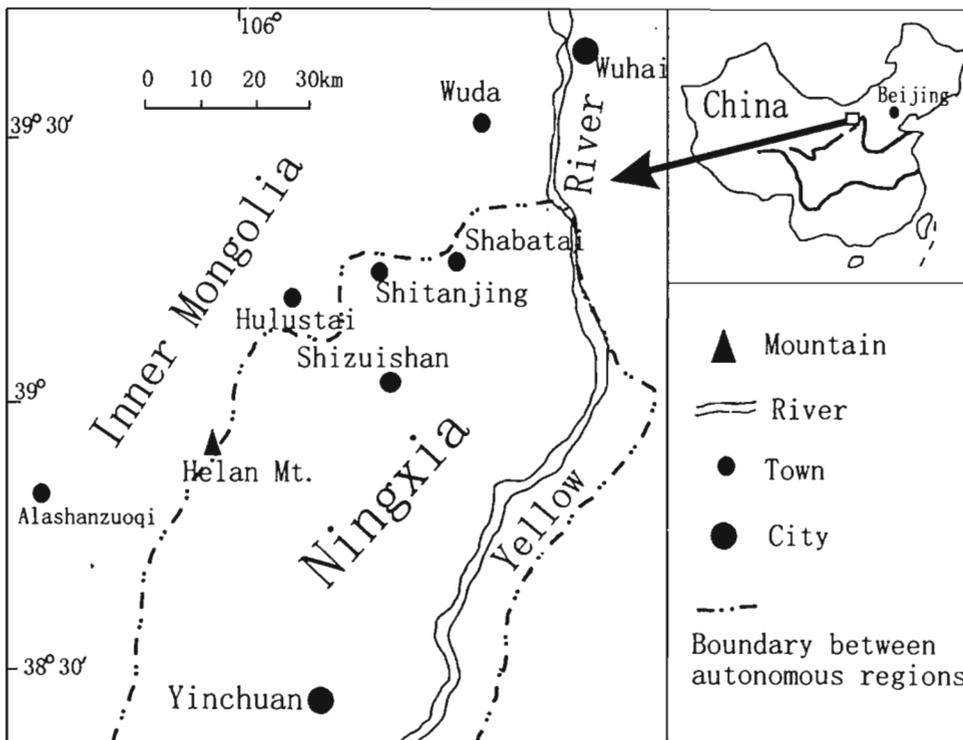

Fig. 1—Map showing the fossil locality.

fossil woods

General representatives of the Cathaysian flora

Platyspiroxylon cf. *heteroparenchymatosum*

Araucarioxylon leei *Zalesskioxylon yimaense*

Ullmannia

Yuania

Chapmanoxylon teilhardii

Araucarioxylon wudense

Araucarioxylon neimongense, Araucarioxylon sp.

Fascipteris

Gigantopteris

Gigantonoclea

Cathaysiopteris

Emplectopteris

Lobatannularia

Protophyllocladoxylon henanense

Cordaioxylon sahnii, Araucarioxylon laoshidanense

Araucarioxylon yichuanense, Zalesskioxylon ningwuense

Shanxioxylon sinense, Sh.taiyuanense, Chapmanoxylon taiyuanensis

Pennsylvanioxylon tianii, P. cf.*nauertianum, Szeioxylon xuzhouense*

Lepidodendron

Cathaysiodendron

Conchophyllum

Tingia

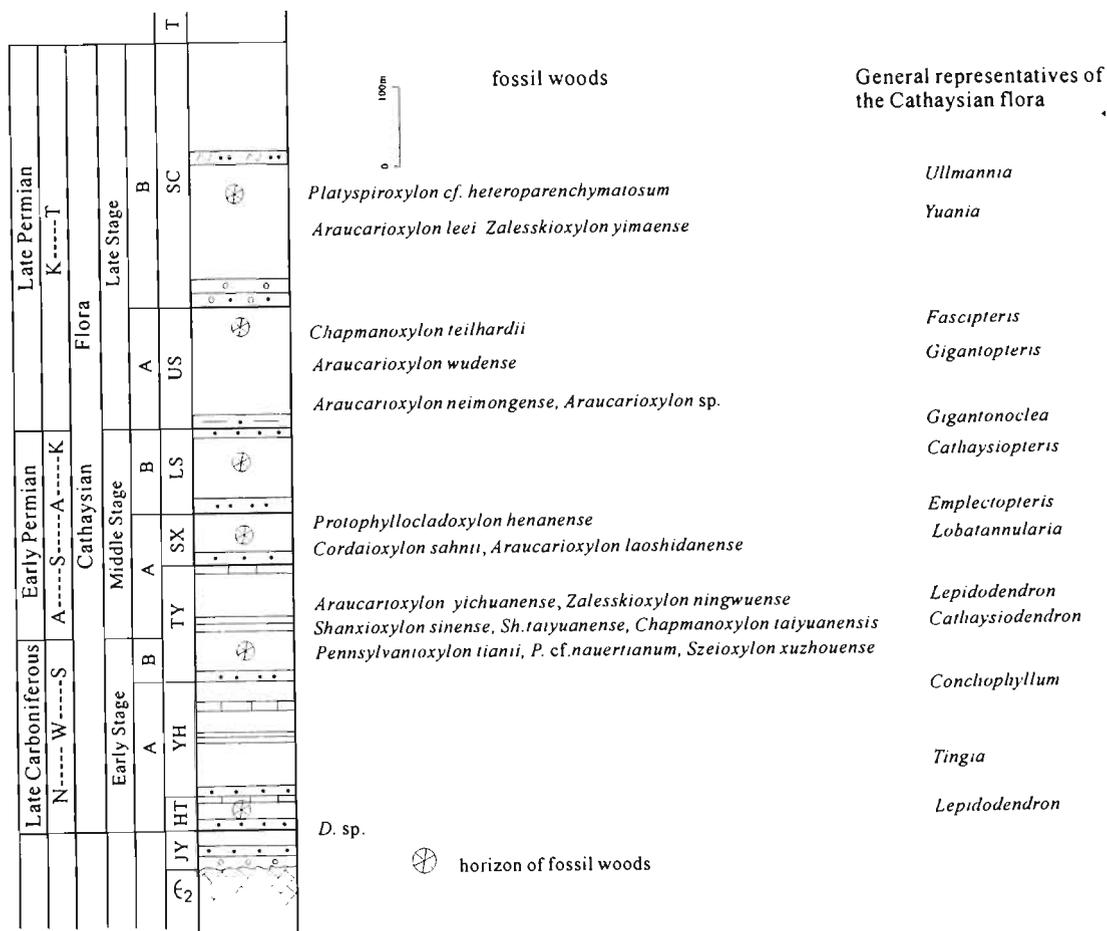*Lepidodendron*

D. sp.

⊕ horizon of fossil woods

Fig. 2— Generalized columnar section of the Permian and Carboniferous in the northern Helan Mountain, as a representative of N. China: showing the stratigraphical occurrences of fossil woods, with contrast to the evolution of the Cathaysian flora (Li, 1997). (N–W–S = Namurian–Westphalian–Stephanian, A–S–A–K = Asselian–Sakmarian–Artinskian–Kungurian, K–T = Kazanian–Tatarian, A, B: floral member of each stage of the Cathaysian Flora). JY=Jingyuan Formation; HT=Hongtuwa Formation; TY=Taiyuan Formation; SX=Shanxi Formation; LS=Lower Shihhotse Formation; US=Upper Shihhotse Formation; SC=Shichienfeng Formation (after Yao et al., 1994, revised).

hexagonal form; generally alternate in multiseriate arrangement; the pits measuring 7·5-10 µm in diameter, pit pore oblong, oblique and crossed, with its large diameter 3/4, short diameter 1/3 of the pit itself. Xylem ray cells roughly rectangular (Pl. 1·3-5), 20 x 150 µm ~ 45 x 415 µm; ray cells little varies horizontally in size, each one spans 3-4 tracheids, as is in accordance with the observation in the transverse section (Pl. 1·1a). Cross-field pits bordered, disordered or horizontally aligned, normally oblique (Pl. 1·5-6).

Tangential section—Xylem rays are homogeneous (Pl. 1·2,2a), about 63% uniseriate, 37% partly biseriate (in 250 counts); rays 1-35 cells high; 70% less than 10 cells, 20% 10-20 cells, seldom more than 30 cells (Fig. 3). The density of rays is about 55 per mm². The ray cells are circular to rectangular with rounded outline, isodiametric or slightly wider than high; when circular measuring 15-45 µm in diameter, usually 30 µm.

Etymology—The specific epithet is after the locality name of autonomous region 'neimongu' the Chinese phonetic alphabet of 'inner Mongolia'.

Holotype—Slides with catalogue No. HEW 169a-c.

Occurrence—Wuda, Alashanzuoqi, Inner Mongolia, China; Upper Shihhotse Formation, Kazanian Stage of Late Permian.

Discussion and Comparison—In China, study on fossil woods mostly followed an authoritative work of 'China Plant Fossils' (Gu & Zhi, 1974), according to which, the present species may be described under the widely described genus *Dadoxylon*. However, the present trends in fossil woods studies, it is preferable to include it in *Araucarioxylon* (more detail hereinafter).

The new species is similar to *Zalesskioxylon rhodeanum* comb. nov. In both the growth rings are not well marked; pits
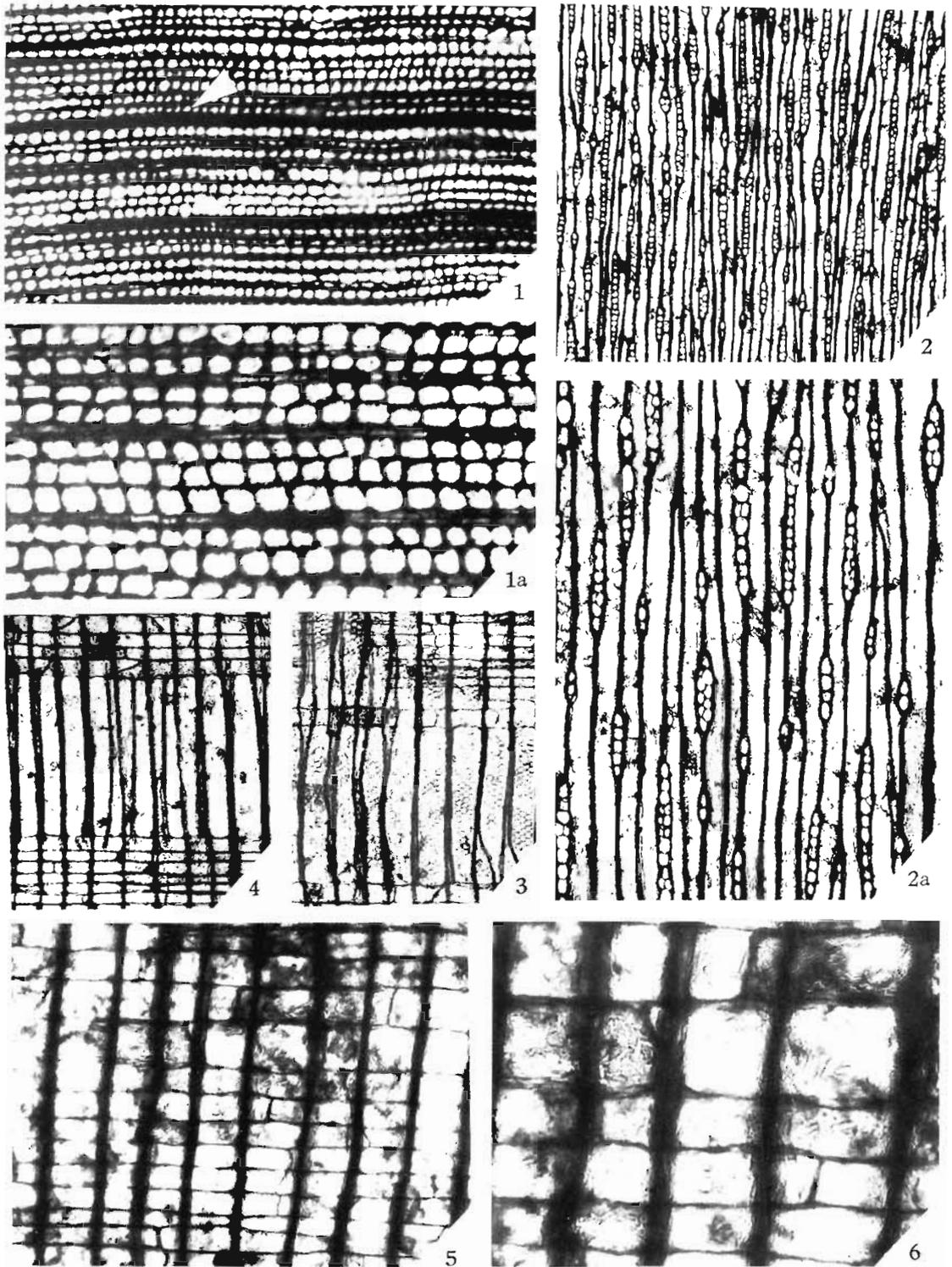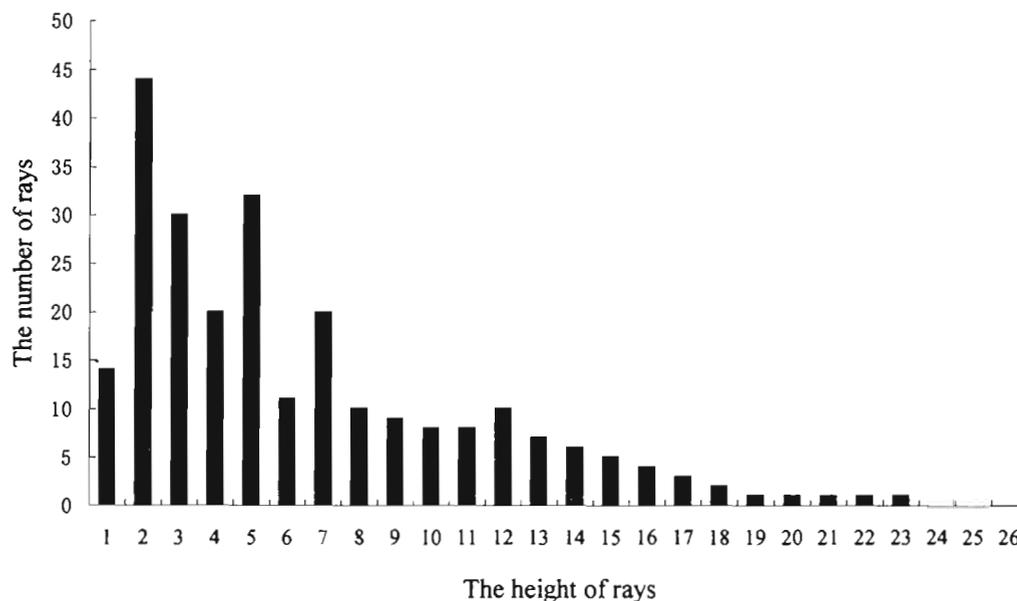
PLATE 1

Fig. 3—Histograms showing the frequency distribution of the height of 250 rays of *Araucarioxylon neimongense* sp. nov. (The height is expressed as the number of cells in tangential longitudinal section, the same in the Figs. 4, 5).

on radial tracheid wall usually 2-4 seriate, rays mostly about 10 cells high, the horizontal wall of ray cells are of the same width or slightly wider than high, and much longer than high in the radial section; each ray cell spans 2-4 tracheids. However, two points of difference are considerable: 1. In *Zalesskioxylon rhodeanum* comb. nov. almost all of pits on tracheids are universally crowded in hexagonal form, while the present new species just partly do so; 2. The rays of *Zalesskioxylon rhodeanum* comb. nov. are uniseriate, rarely partly biseriate; while in the new species biseriate rays are not rare (more than 1/3), and furthermore, such a large proportion of biseriate rays may be treated as one diagnostic character of the new species among all known fossil woods in the Cathaysian flora.

Dadoxylon weaverense Maheshwari (1972) and *D. lukugense* Grambast (1960) also have a high percentage of biseriate rays, the former with 75% rays partially or wholly biseriate, 1-21 cells high; the latter one with 25% rays partially biseriate, 1-61 cells high; such that both are distinguished from the present new species.

ARAUCARIOXYLON WUDENSE sp. nov.

(Pl. 2·1-5; Pl. 3·1-6; Figs 4, 5)

Diagnosis—Growth rings poorly developed, radial pitting araucaroid, 1-3 seriate (triseriate uncommon); xylem rays about 60% uniseriate, 40% partly biseriate in 1-6 cells high or even more; 1-40 cells high; cross-field pits bordered, 1-9 (usually 2-5) in number. Resin canals absent; but xylem rays usually filled with dark material.

Description—The species is represented by a block of silicified trunks, where only the secondary wood is preserved. Growth rings can be discerned microscopically.

Transverse section—To the naked eye it shows very marked regular concentric circles of the growth rings, about 15 in number; outer one width 5 mm, inner one 2-3 mm. However, microscopically only several rings can just be carefully discerned. The early wood is much wider than the late wood, which is usually 3-4 tracheids wide (Pl. 2·1; Pl. 3·1); spring tracheids 50 μm in diameter when circular, 50 x

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PLATE 1

Araucarioxylon neimongense sp. nov.

1. Transverse section showing tracheids, xylem rays and a poorly developed growth ring (arrow). Cat. No. HEW 169a (slide of the holotype). x 50.

1a. Part of 1 in magnification showing the orderly arrangement of tracheids and the ray cells. x100.

2. Tangential section showing uniseriate and partly biseriate xylem rays. Cat. No. HEW169c (slide of the holotype). x 50.

2a. Part of 2 in magnification showing the form of ray cells. x 100.

3. Radial section through the secondary xylem showing multiseriate

bordered pits in alternate arrangement, partly crowded in hexagonal form. Cat. No. HEW 169b (slide of the holotype). x 100.

4. Radial section showing uni- to biseriate bordered pitting and the form of the ray cells; pits separate, contiguous, or alternate, usually circular. The same slide with 3. x 100.

5, 6. The bordered cross-field pits, 2-9 in number. At the lower part of 6, circular uncrowded pits can be observed. The same slide of HEW 169b. 5, x 200; 6, x 400.
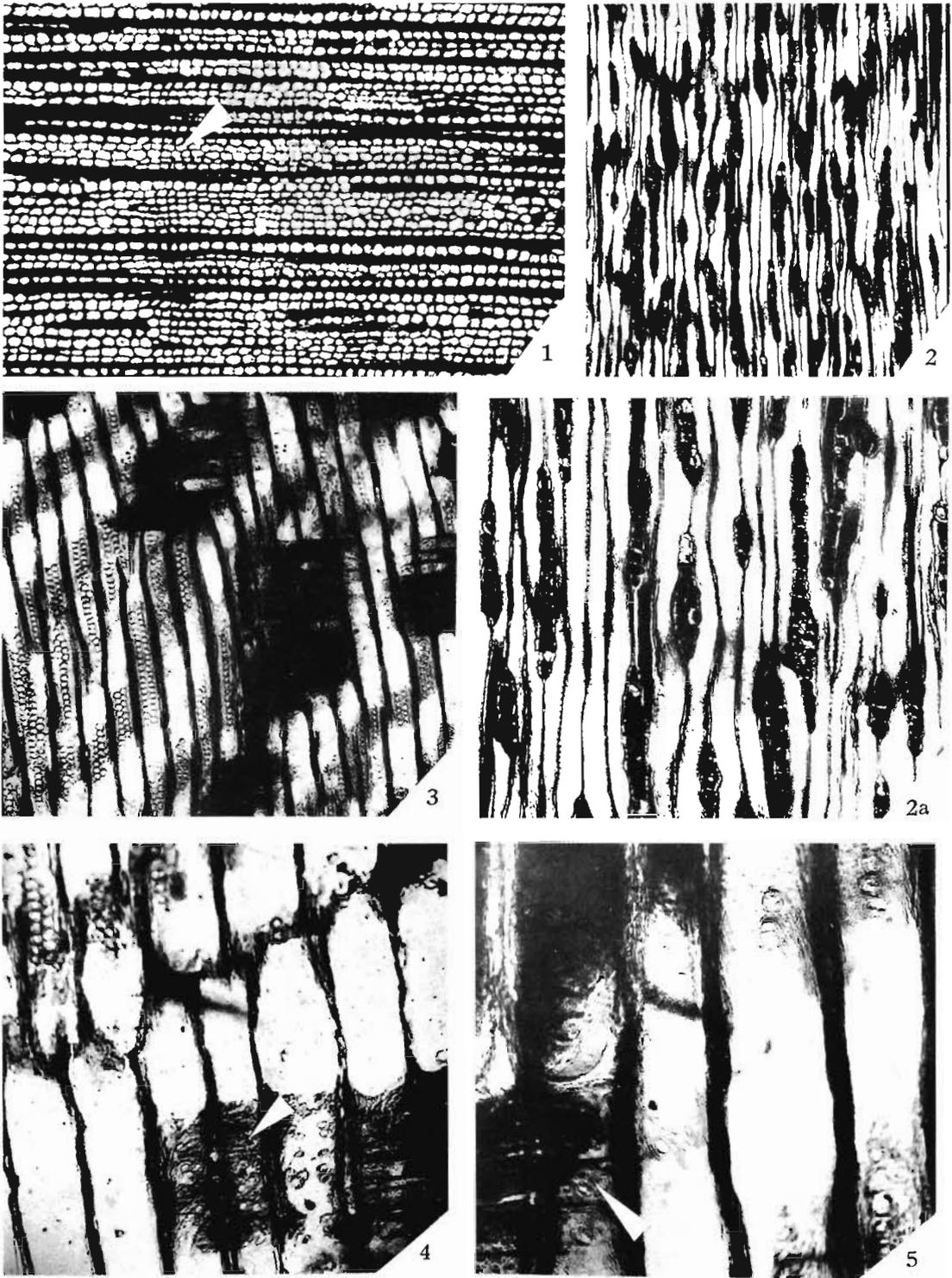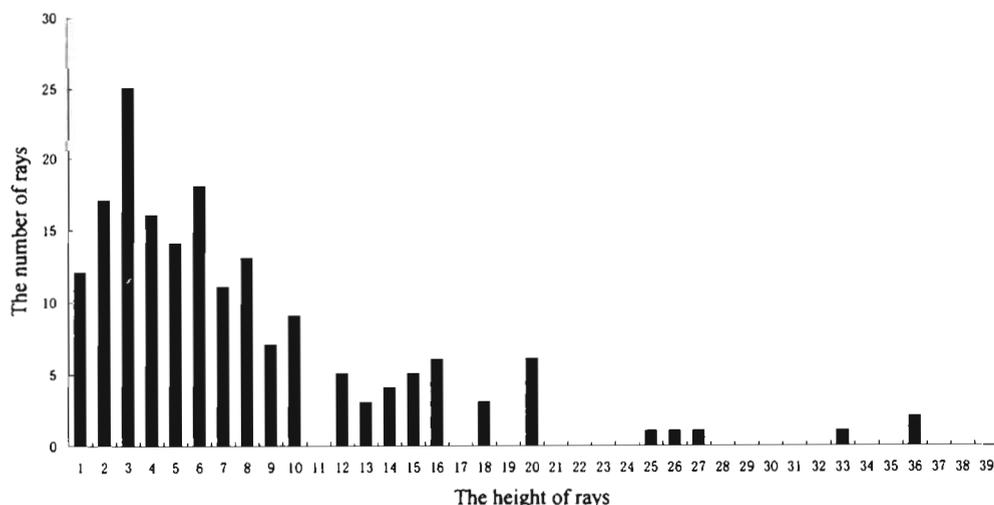
PLATE 2

Fig. 4—Histograms showing the frequency distribution of the height of 200 rays of *Araucarioxylon wudense* sp. nov. (Holotype)

60 μm when elliptical or 15 x 60 μm when rectangular; autumn tracheids circular, 25 μm in diameter, or rectangular with rounded outline, 25 x 35 μm ~ 25 x 50 μm in dimension. Xylem rays and some tracheids are filled with black material, which may be related to resin. On the whole, tracheids in this section are mostly rectangular or elliptical in shape and seem to be arranged in an orderly fashion.

Radial section—The radial pitting is of the characteristic araucaroid type (Pl. 2·3; Pl. 3·3). The pits are usually uniseriate and biseriate, occasionally triseriate. They are usually alternate and hexagonal when 2-3 seriate, sometimes still circular; when uniseriate, pits are mostly contiguous, circular, or flattened by contact, rarely separate; pit pores circular or elliptical, whose larger diameter is horizontal or oblique. In favorable cases the cross-field pits can be seen clearly (Pl. 2·4, 5; Pl. 3·4-6), bordered, 1-9 in number, mostly 2-6, elliptical, separate and disordered or horizontally aligned; ray cells trapezoidal, measuring about 25 x 240 μm, mostly 8-10 times longer than high; normally one cell spans 3-5 tracheids. Pits when circular 8–13 μm in diameter, when elliptical or hexagonal 10-13 x 15-18 μm; pit pore when circular, with its diameter 1/3 length of the pit itself; when elliptical with the large diameter 1/2, small diameter 1/3 of pit itself; the radial walls of tracheids measure 10-13 μm in thickness.

Tangential section—Xylem rays are homogeneous (Pl. 2·2,2a; Pl. 3·2,2a) and mainly uniseriate, nearly 40% (in 200 counts) are partly biseriate for 1-8 cells or even more; 1-36 cells high, average 8 cells, mainly 1-10 cells; 10-20 cells are not unusual, and occasionally more than 30 cells high, as could be evidenced by a statistical analysis of the height of rays in 200 counts shown in Figs 4-5. Rays vary from 50 to 1480 μm in height, with an average height of 270 μm; ray cells are normally rectangular with rounded outline, 30 x 45 μm when uniseriate, while biseriate ray cells are a little smaller, 20~25 μm in diameter. Generally, ray cells are 10-50 μm high, average 20 μm; 10-50 μm in breadth, average 30 μm. The density of rays is 22 per mm².

There are no pits and spiral thickenings on the tangential walls of the tracheids, but the bordered pits in the radial walls are clearly visible in this section.

No resin canals were observed although the ray cells and some tracheids are filled with dark material, possibly of resinous in nature.

Etymology—The specific epithet is after the name of the locality 'wuda', the Chinese phonetic word for the small town.

Holotype—Slides with catalogue No. HEW 170a-c
Paratype—Slides with catalogue No. HEW 166a-c.

PLATE 2

Araucarioxylon wudense sp. nov. (Holotype)

1. Transverse section showing the faint growth ring with breadth of 3-4 rays of tracheids (arrow), and the transition from the late to early wood. Cat. No. HEW 170a (slide of the holotype). x 50.
2. Tangential section of the secondary wood showing the form of xylem rays; ray cells are filled with dark substance. Cat. No. HEW 170c (slide of the holotype). x 50.
2a. A part of 2 in magnification showing the uni- to partly biseriate xylem rays, and the unpitted tangential walls of tracheids. x 100.

3. Radial section showing the form of bordered tracheids pits, uni- to biseriate, contiguous, alternate and rarely separate; crowded in hexagonal form or not. Cat. No. HEW 170b (slide of the holotype). x 100.
4, 5. Radial section showing the bordered pits in cross-field, 2-5 in number. At some places the pits appear to be filled with dark material (arrow). The same slides with 3. 4. x 200; 5. x 400.
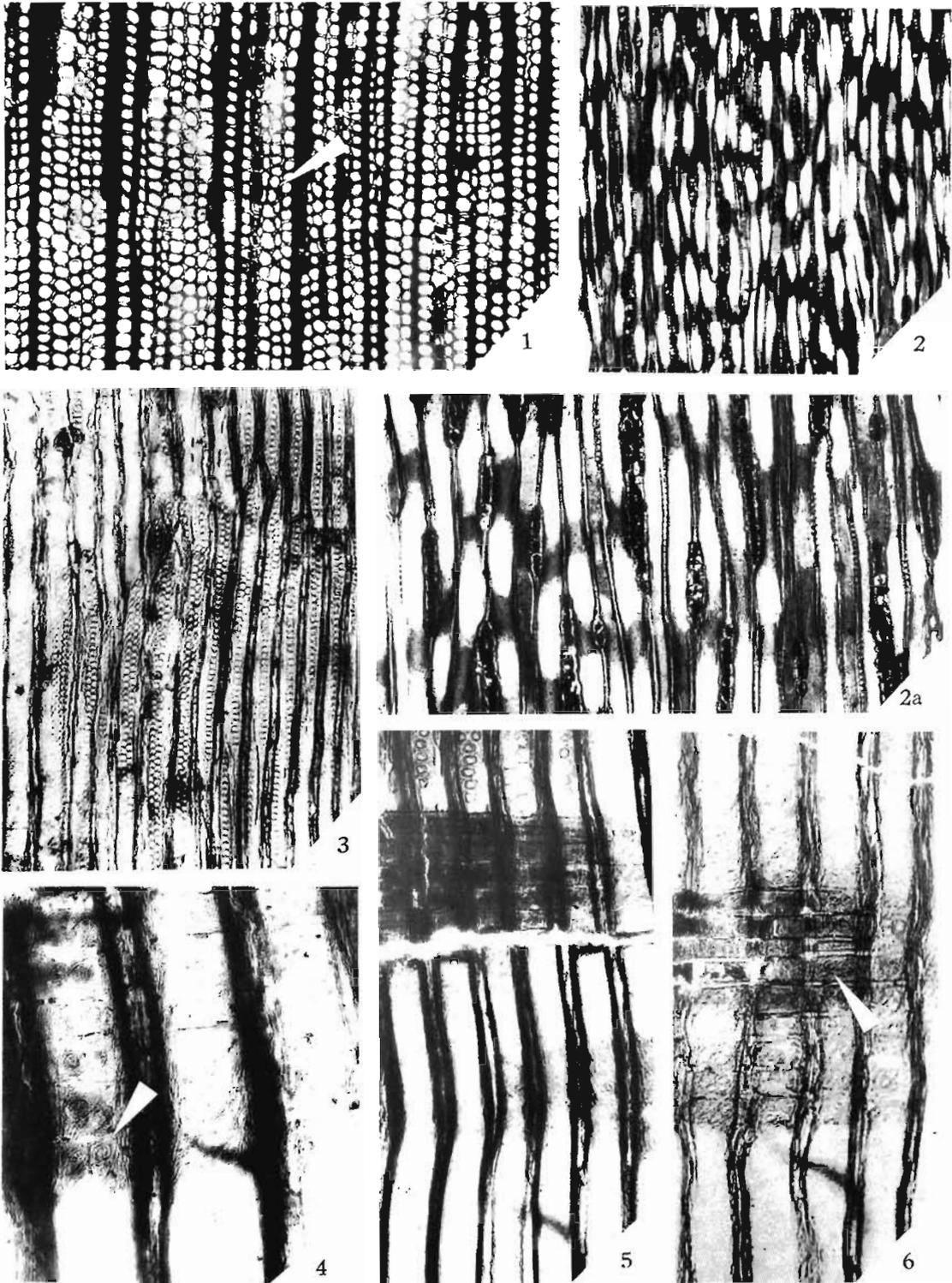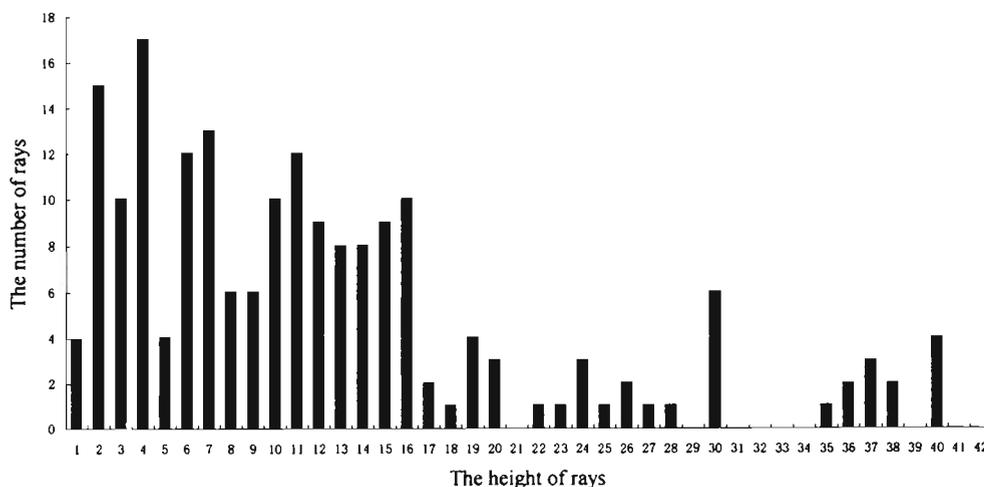
PLATE 3

Fig. 5—Histograms showing the frequency distribution of the height of 200 rays of *Araucarioxylon wudense* sp. nov. (Paratype).

Occurrence—Wuda, Alashanzuoqi, Inner Mongolia, China; Upper Shihhotse Formation, Kazanian Stage of Late Permian.

Comparison—The new species could be definitely distinguished from the previous known fossil woods in the Cathaysian flora by the presence of nearly 40% partly biseriate rays. The rays of those known species are all uniseriate, and rarely partly biseriate. Particularly, it is necessary to point out that although *Araucarioxylon neimongense* sp. nov. is also characteristic for nearly 40% (accurately 37% in 250 counts) of partly biseriate xylem rays, the present new species differs from *Araucarioxylon neimongense* sp. nov. in three critical points: (1) it has less (1-2, occasionally 3) seriate of radial pits than the former (1-5, mostly 2-4 seriates); (2) its rays more than 30 cells high are not uncommon, while the ray height of *Araucarioxylon neimongense* sp. nov. seldom reach 30; (3) its density of rays is 22 per mm^2, considerably lower than that of *Araucarioxylon neimongense* sp. nov. (55 per mm^2).

Dadoxylon chandaensis Chitaley (1949), is similar to the present species in radial pits 1-2 seriate (rarely 3 seriate), rays 1-2 seriate, 1-33 cells high; but considerably different from the present one in the simple cross-field pits and the appearance of pits in tangential wall of tracheids.

D. sahnii Singh (1958) is comparable with the present species in 1-2 (rarely 3) seriate pits in radial wall of tracheids; rays 1-2 seriate, height may reach 39 cells; but can be distinguished by lack of 1-2 cells high rays and the simple cross-field pits.

Remarks—The paratype has a little difference from the holotype in the generally higher rays (see Figs 4-5), and the comparatively fewer rays partly biseriate in 6-8 cells. Nevertheless, they show a close affinity with each other in such critical aspects as: (1) black material filled rays and part of tracheids; (2) the form and arrangement of tracheid pits; (3) Numbers of bordered cross-field pits; (4) density of rays; so that the limited differences could be treated as infraspecific variations.

?ARAUCARIOXYLON sp.

(Pl. 4·1-6)

Description—The specimens include several pieces of trunks found in the locality and stratigraphical horizon of the former new species, with only secondary wood preserved, with catalogue No. HEW 165a-c. Growth rings are well marked.

PLATE 3

Araucarioxylon wudense (Paratype)

1   Transverse section showing the form of tracheids and dark material-field rays. A zone of slightly diminished diameter of 3-4 rays of tracheids might mark the poorly developed growth ring. Cat. No. HEW 166a x 50.

2.   Tangential section showing the form of xylem rays, which are filled with black material. Cat. No. HEW 166c, x 50.

2a.   A part of 2 in magnification showing uni- to partly biseriate xylem rays and the unpitted tangential wall of tracheids; the pits on radial walls can be observed. x 100.

3.   Radial section showing the uni- to biseriate pits of the tracheids. contiguous, alternate and circular or crowded in hexagonal form. Cat. No. HEW 166b. x 100.

4, 5, 6.   Radial sections showing cross-fields. There is 1-6 (usually 2-4) bordered pits in each cross-field. At some places, the pits appear to be filled with black substance (arrow). The same slide with 3. 4, x 400; 5, 6. x 200.
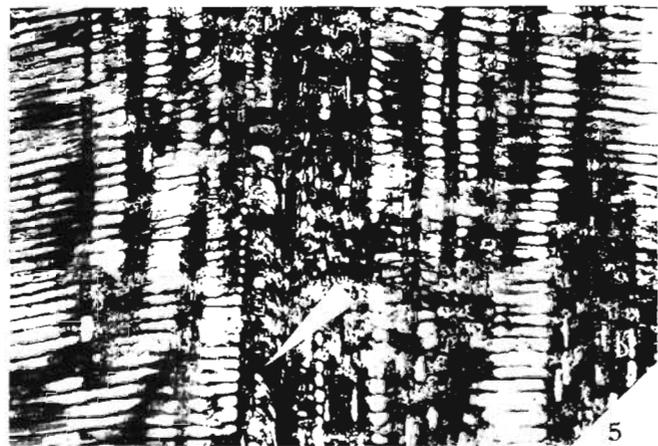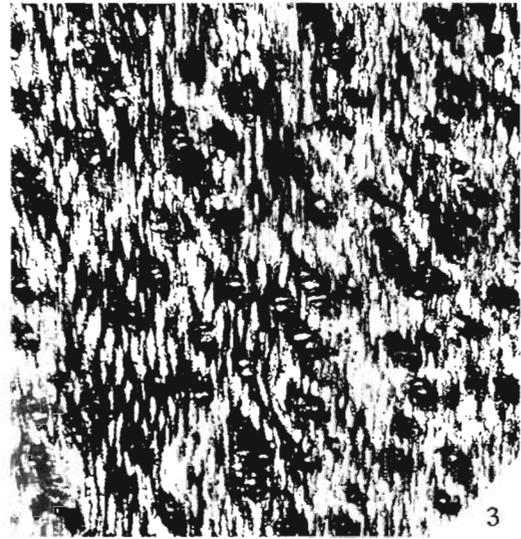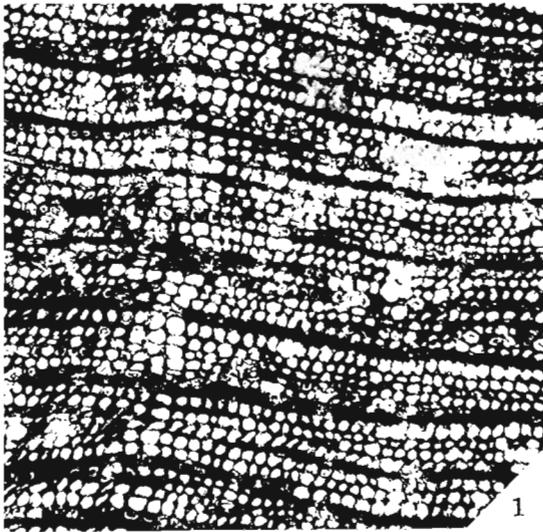
PLATE 4

The secondary wood was deformed and can not be cut in a well-defined tangential or radial section.

Transverse section—Growth rings relatively well marked (Pl. 4·1), particularly the inner two, with a width of 2 mm each; one branch trace is present and filled with dark material (Pl. 4·2), which may be resinous in nature, and in some cases, certain spiral thickenings could be seen. Tracheids fairly irregular, circular, elliptical, rectangular or polygonal with rounded outline.

There is a well-marked transition from the early wood to the late wood; circular tracheids normally have diameter of 55 μm in the early wood, and 30 μm in the late wood.

Tangential and radial sections—Due to poor preservation and distortion, the tangential and radial sections are not clear. Nevertheless the following characteristics may be seen: tracheid pits only occur on radial walls, mostly uniseriate, others biseriate; when uniseriate, usually contiguous, sometimes separate; when biseriate, alternate in arrangement; circular or crowded in hexagonal form; the circular ones have a diameter of 13-15 μm, and usually uniseriate pits are a little larger than biseriate ones. Sometimes pit pores are very small, when circular, diameter only 1/5-1/6 of the pit itself. Xylem rays are homogeneous (Pl. 4·3), uniseriate, rarely partly biseriate for one or two cells. 2-15 cells high, mostly 2-6, and usually wider than high, but this may be ascribed to the fact that the section is not strictly tangential. The density of the rays is 30 per mm². Ray cells are radially rectangular, with a height 30-40 μm, length 125-200 μm; in favorable cases, radially spiral thickenings on the tracheids of a branch could be seen (Pl. 4·2,5a); cross-fields are not clearly seen.

Discussion and comparison—Fossil woods where a pith and primary xylem are unknown generally are described in three genera, viz., *Araucarioxylon, Zalesskioxylon* and *Protophyllocladoxylon*, on the basis of different cross-field pits. Due to the uncertain character of cross-field pits, the species may also be described in *Zalesskioxylon* or *Protophyllocladoxylon*. It has been provisionally put under *Araucarioxylon* due to its similarities with Lepekhina's *Araucarioxylon* sp. from Upper Permian of Kuznetsk Basin (Lepekhina, 1972) in the well marked growth ring, dark or brown substance-filled xylem rays and their height, as well as their uniseriate rays size. However, they are not identical in

the density of rays (Lepekhina's *Araucarioxylon* sp. has only 7 per mm²). Furthermore, both of their cross field are unknown.

To a certain extent, *Chapmanoxylon* ? *teilhardii* (Sze) comb. nov. is similar to the present species in the arrangement of tracheid pits, lower rays and well-marked growth rings. In the present species, however, xylem rays are filled with abundant dark material of a resinous nature. Additionally, its cross-field pits are uncertain.

In addition, comparing with *Araucarioxylon laoshidanense*, which was recently recognized from the current locality, all of the present three species only have alternate pits on radial tracheid wall, while those of *A. laoshidanense* are mixed, mostly alternate but sometimes opposite. Meanwhile, apart from the unknown cross-field pits on *Araucarioxylon* sp., the cross-field pits of *A. laoshidanense* are remarkably less than those of *A. neimongense* sp. nov. and *A. wudense* sp. nov.

TAXONOMIC CONSIDERATIONS: ON THE PALAEOZOIC ARAUCAROID WOODS IN THE CATHAYSIAN FLORA

Among the remarkable four distinctive floras, namely, Angaran, Eurammerican, Gondwanan and Cathaysian flora on the Palaeozoic earth, Cathaysian flora is the one in which fewest fossil woods are recorded. By far, total 20 species have been reported* formally (see Fig. 8), and all were distributed over China. Particularly, the araucaroid woods in which are mostly included in *Dadoxylon sensu lato* in last several decades, according to the authoritative work of Gu and Zhi (1974), in which the *Dadoxylon* was defined as (p. 161 in Chinese): radial pits of tracheids bordered; oblate or elliptical when uniseriate; when biseriate or multiseriate, alternate in arrangement, mostly crowded in polygonal form, occasionally separate in circular shape. Xylem parenchymous, cell absent, rare, or replaced by tracheids containing resin; xylem rays uniseriate, rarely biseriate. The horizontal and tangential wall of tracheids smooth; pits in cross-field simple or bordered, 1-

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* Halle T.G. 1935, stems of *Walchia* were reported from Nanshan in Gansu, but anatomically indeterminable.

PLATE 4
?*Araucarioxylon* sp.

1. Transverse section showing the form of tracheids and xylem rays. One well marked growth ring is observed. Cat. No. HEW 165a. x 70.

2. Transverse section showing a branch trace filled with dark material. In favorable case, spiral thickenings on the horizontal wall of the ray cells can be seen (arrow). The same slide with 1. x 50.

3. Tangential section showing the uniseriate (rarely partly biseriate) rays with several cells of height; tangential wall is unpitted; pits on the radial wall of tracheids can be seen. Cat. No. HEW 165c. x 50.

4. Radial section of the secondary wood through xylem rays showing the form of tracheids. Uniseriate pits are mostly seen; crossfields are uncertain. Cat. No. HEW 165b. x 100.

5. Radial section showing a branch trace. Generally, it looks like a xylem ray, but differ in a transitional zone to tracheids (arrow). The same slide with 4. x 50.

5a. A part of 5 in magnification showing the spiral thickenings on the radial wall of the tracheids in the branch. x 200.

Fig. 7— Comparative characters of the fossil woods from the Carboniferous and Permian of China.

Species	Pith	Primary Xylem	Pits in radical tracheidal walls	Xylem rays	Cross-field pits	Locality	Horizon	Growth ring	Reference
Chapmanoxylon ? *teilhardii* (Sze) comb.nov.	1cm diameter, contiguous parenchymatous	endarch (?)	biseriate, occasionally uni- or triseriate, contiguous or separate, alternate	homogeneous, uniseriate, 1-6 (rarely more than 8) cells high	3-6, simple (?)	Datong	Upper Shihhotse Fm.	+++	Sze,1934; Gu & Zhi,1974
Chpamanoxylon ? *taiyuanensis* (Li) comb. nov.	2-3 mm diameter, solid	endarch	1-2 seriate	uniseriate, rarely partly biseriate,1-14 cells high	1-2,	Taiyuan	Taiyuan Fm.	+	Li, 1986
Cordaioxylon sahnii (Hsu & Bose) com.nov.	septate, 17/cm	uncertain	1-2 (occasionally 3) seriate, alternate	homogeneous, uniseriate, rarely partly biseriate, 1-10 (usually 1-4) cells high, 43 per mm²	1-4 (usually 1), bordered	Taiyuan	Taiyuan Fm, Shanxi Fm.	×	Hsu & Bose, 1952; Gu & Zhi,1974
C houtouguense (Zhang & Zheng) comb. nov.	septate, 5-6/cm, parenchymatous and stone cells	endarch	1-3 (rarely 4) seriate, alternate (araucaroid)	uniseriate, rarely partly biseriate, 1-3 cells high	3-5, simple				
Araucarioxylon leei (Sze) comb. nov.			uniseriate rarely biseriate	uniseriate, rarely partly biseriate, 1-22 (average 6) cells high	1, small, bordered	Yaoxian	Shichiefeng Fm.	+	Sze, 1952; Gu & Zhi, 1974
Araucarioxylon yichuanense Yao Liu & Zhang			1-4 (usually 2-3) seriate, contiguous or separate, alternate (araucaroid)	homogeneous, rarely partly biseriate, 1-21 (average 5) cells high, ray cells 103 per mm²	4-11 (occasionally 15), bordered	Yichuan	Taiyuan Fm.	+	Yao et al., 1994
Araucarioxylon laoshidanense Wang Hu & Cui			1-4 (commonly 2 or 3) seriate, mostly alternate but sometimes opposite	uniseriate, sometimes partly biseriate; 2-39 (mainly 3-5) cells high	1-4 (commonly 1, rarely 2-4), bordered	Wuda	Taiyuan Fm.	×	Wang et al., 2000
Araucarioxylon neimongense sp. nov.			1-5 seriate (most 2-4), contiguous or separate, alternate (araucaroid)	homogeneous, 37% partly biseriate, 1-35 cells high, rays 55 per mm²	1-7 (usually 3-5), bordered	Wuda	Upper Shihhotse Fm.	+	the present paper
Araucarioxylon wadense sp. nov.			1-3 (usually1-2) seriate, contiguous or separate, alternate (araucaroid)	homogeneous, 40% partly biseriate, 1-36 cells high, rays 26 per mm²	1-9 (usually 2-6), bordered	Wuda	Upper Shihhotse Fm.	+	the present paper
A. sp.			1-2 seriate, contiguous or separate, alternate (araucaroid)	homogeneous, rarely partly biseriate, 2-15 (mostly 2-6) cells high, 30 per mm²	uncertain	Wuda	Upper Shihhotse Fm.	++	the present paper
Zalesskioxylon rhodeanum Goepp. comb. nov. (species from China)			2-4 (occasionaly 1) seriate, alternate	homogeneous, uniseriate, sometimes partly biseriate, 1-20 (mostly 1-12) cells high	3-5, simple	Taiyuan, Yangquan, Jingxing, Laiwu, Hulustai	Permian (no more detail position)	×	Gu & Zhi, 1974; Gothan & Sze, 1933

Species	Pith	Primary Xylem	Pits in radical tracheidal walls	Xylem rays	Cross-field pits	Locality	Horizon	Growth ring	Reference
Zalesskioxylon ningwuense (Chang Zhang & Zhao) comb. nov.		1-2 (rarely 3)	seriate, alternate or sub-opposite (araucaroid)	uniseriate, rarely partly biseriate, 1-14 cells high, rays 17 per mm²	1-6, simple	Ningwu	Taiyuan Fm.	+	Chang *et al.*, 1993
Zalesskioxylon yimaense (Yao Liu & Zhang) comb. nov.			uniseriate, sometimes biseriate (araucaroid)	homogeneous, uniseriate, rarely partly biseriate, 2-31 (average 9) cells high, ray cells 178-222 per mm²	2-5 (usaully 2-3), simple	Yima	Shichiefeng Fm.	+ +	Yao *et al.*, 1994
Z. xiuqiense (Zhang & Zheng) comb. nov.			1-5 (usually 3-4) seriate	uniseriate, rarely partly biseriate, 2-10 cells high	7-15, simple				
Dadoxylon. sp.						Jingyuan	Hongtuwa Fm.	×	Tian *et al.*, 1995
D. sp.						Pingding-shan	Upper Shihhotse Fm.	++	Sze, 1954
Protophyllocladoxylon henanense Yao Liu & Zhang			uniseriate, sometimes biseriate (araucaroid)	homogeneous, uniseriate, rarely partly biseriate (33%), 1-40 (average 12) cells high, ray cells 214 per mm²	1 (rarely 2), simple	Pingding-shan	Shanxi Fm.	×	Yao *et al.*, 1994
Shanxioxylon sinense Tian & Wang	9 mm diameter, septate, parenchymatous and chambered	stem endarch, leaf trach mesarch	1-3 (usually 2) seriate	uniseriate, 1-9 (usually 3-4) cells high	uncertain	Taiyuan	Taiyuan Fm.	×	Tian & Wang, 1987
S. taiyuanense Tian & Wang	12mm diameter, parenchymatous and chambered	stem endarch, leaf trach mesarch	biseriate, alternate	uniseriate, 1-18 (usually 4-5) cells high	1-4 in number	Taiyuan	Taiyuan Fm.	×	Tian & Wang, 1987
Pennsylvanioxylon tianii Tian & Wang	4mm diameter, parenchymatous and chambered	stem endarch, leaf trach endarch	multiseriate, alternate	uniseriate, 1-4 cells high	uncertain	Taiyuan	Taiyuan Fm.	+++	Tian & Wang, 1987
P. cf. *nauertianum*						Zhaozhuang, Yanzhou	Taiyuan Fm.	×	Wang, 1989
Szeioxylon xuzhouense Wang Jiang & Qin			2-5(usually 3-4) seriate, alternate or rarely sub-opposite (araucaroid)	uniseriate, partly biseriate is not unusual, 1-45 (usually 2-8) cells high, ray tracheids present	2-4 bordered (cupressoid)	Xuzhou	Taiyuan Fm.	×	Wang *et al.*, 1994
Platyspiroxylon cf. *heteroparenchymatosum* Greguss						Liulin	Shichiefeng Fm.	++	Wang, 1985

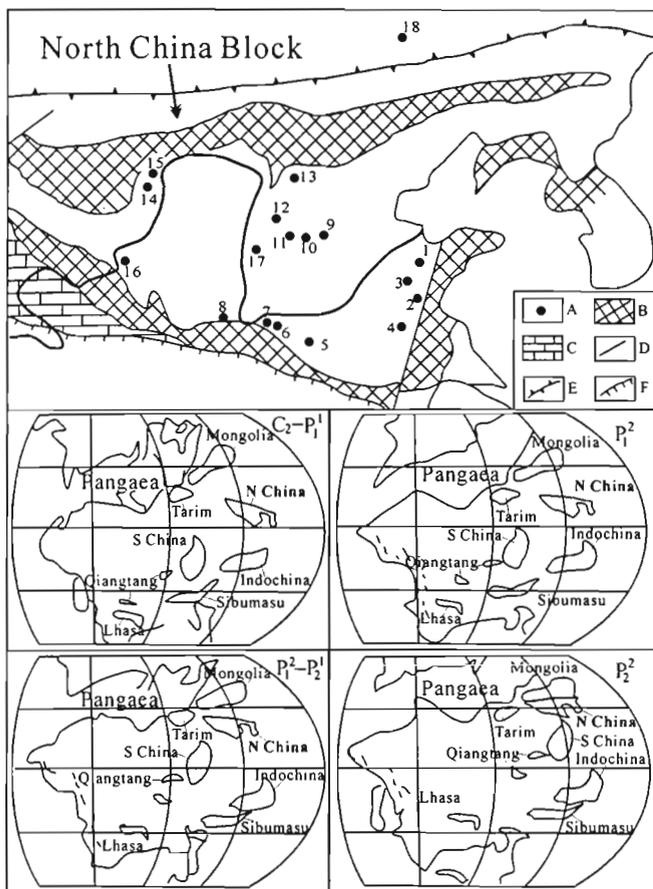× = absent; + = present but not very clear; ++ = present and remarkable; +++ = present and very distinct.

Fig. 6— Localities of Palaeozoic fossil wood in the N China Block (Base map after Zhang Hong, 1991), and the block's drifting process in the Palaeotethys. (Base map after Wang Yue, 1998) (Locality 18, i.e. Xiwuzhumuqi is not on this block, shown on the sketch map because of being referred in the text.)
A. Locality of fossil woods, primarily distributing on Land sediment; B. Denuded zone; C. Marine deposit; D. Shove fault formed at later stage; E. Zone of block juncture or block subduction at later stage. Localities: Shandong: 1. Laiwu. 2. Zhaozhuang, 3. Yanzhou; Jiangsu: 4. Xuzhou; Henan: 5. Pingdingshan, 6. Yichuan, 7. Yima; Shaanxi: 8. Yaoxian; Hebei: 9. Jingxing; Shanxi: 10. Yangquan, 11. Taiyuan, 12. Ningwu, 13. Datong, 17. Liulin; Inner Mongolia: 14. Hulustai. 15. Wuda; Gansu: 16. Jingyuan.

15 in number. Furthermore, it was remarked that as a form genus, *Dadoxylon* might include fossil woods possibly belonging to Cordaitopsida, Lebachiaceae and Araucariaceae of Coniferae; and one specimen without definite systematic affinity could be designated in this genus, if only it takes the possession of the above mentioned characteristics. Such a wide meaning of *Dadoxylon* distinguishing neither woods with or without 'pith and primary xylem, nor type of cross-field pits, actually makes it a wide group of woods rather far from being a closely defined genus of woods.

Such a situation is however, widely prevalent and the taxonomy of Palaeozoic woods is fairly confusing. Opinions on the taxonomy of araucaroid woods vary, and each view has a group of supporters. There have been many studies attempting to improve (e.g., Zheng, 2000; Prasad, 1982; Lepekhina & Yatsenko, 1966; Greguss, 1961; Seward, 1917, 1919; Gothan, 1905; Zeiller, 1900, and other authors), among which, the latest suggestions of Pant and Singh (1987) is comprehensively advisable: *Dadoxylon* should be replaced by a new proposed Genus *Chapmanoxylon*, because " its widely recognized generitype, *Dadoxylon withamii* (Lindley & Hutton) Endlicher; has been transferred to *Pitys* (*Pitus*) Witham, by Goeppert (1881) on account of its mesarch primary xylem and manoxylic secondary wood with multiseriate xylem rays and a wide pith (the pith and primary xylem of this wood were neither mentioned by Lindley & Hutton, 1831, nor by Endlicher 1847; but Scott, 1902 described it as having a wide pith and mesarch primary xylem)", and therefore *Dadoxylon* should be rejected.

The present author agrees with Pant and Singh's recommendation on the point of the classification and taxonomy of araucaroid woods. It is quite beyond the scope of the present paper to provide their suggested system in detail, but it may be summarized as follows (Pant & Singh, 1987, p. 69) (Fig. 8):

It is in accordance with this system of classification and taxonomy of araucaroid woods, that the present species are identified. In addition, with respects to the simple system, the known Palaeozoic araucaroid woods in China, actually can get the following assignment, and certain new combinations are recognized:

Protophyllocladoxylon Krausel, 1939
    P. henanense Yao Liu & Zhang,
Araucarioxylon Kraus, 1870
    Araucarioxylon leei (Sze) comb. nov.
    Araucarioxylon yichuanense Yao, Liu & Zhang
    Araucarioxylon laoshidanense Wang, Hu & Cui
    Araucarioxylon neimongense sp. nov.
    Araucarioxylon wudense sp. nov.
    Araucarioxylon sp.
Zalesskioxylon Lepekhina & Yatsenko, 1966
    Zalesskioxylon xiuqiense (Zhang & Zheng) comb. nov.
    Zalesskioxylon yimaense (Yao, Liu & Zhang) comb. nov.
    Zalesskioxylon ningwuense (Chang, Zhang & Zhao) comb. nov.
    Zalesskioxylon rhodeanum Goepp. comb. nov. (the species found in China)
Chapmanoxylon Pant and Singh, 1987
    Chapmanoxylon ? *taiyuanense* (Li) comb. nov.
    Chapmanoxylon ? *teilhardii* (Sze) comb. nov.
Cordaioxylon Grand'Eury 1877
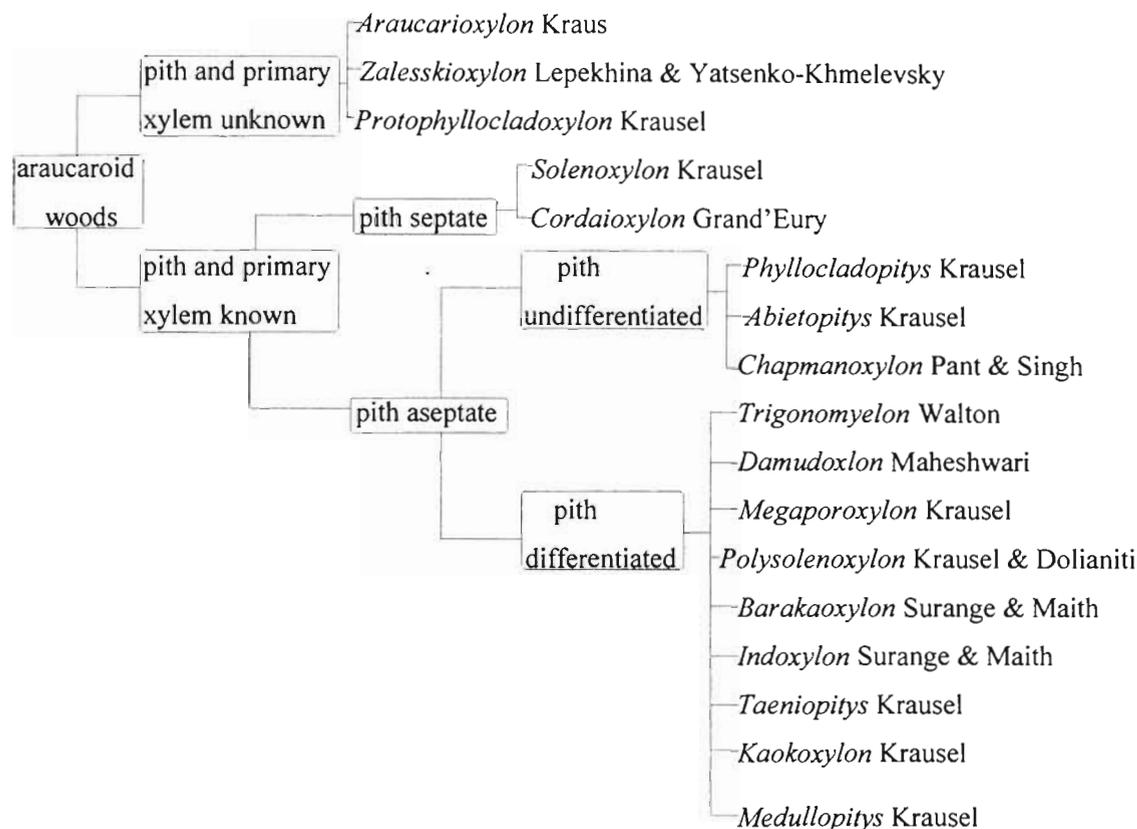   *Cordaioxylon sahnii* (Hsu & Bose) comb. nov.

Fig. 8—After Pant & Singh (1987, p 69).

Cordaioxylon houtouguense (Zhang & Zheng) comb. nov.

On the above-recognized new combination the following explanation is necessarily referred:

Previously, *Araucarioxylon leei* (Sze) comb. nov., *Zalesskioxylon xiuqiense* (Zhang & Zheng) comb. nov., *Zalesskioxylon ningwuense* (Chang, Zhang & Zhao) comb. nov. and *Zalesskioxylon rhodeanum* Goepp. comb. nov. (the species found in China) were described in *Dadoxylon*. Their pith and primary xylem are entirely unknown, and they are here reassigned respectively to *Araucarioxylon* because of the bordered cross-field pits, and to *Zalesskioxylon* for having simple cross-field pits. *Zalesskioxylon yimaense* (Yao, Liu & Zhang) comb. nov. was included in *Araucarioxylon*, since its pith and primary xylem are unknown, but it has simple cross-field pits, and is accordingly transferred here under *Zalesskioxylon*.

Chapmanoxylon ? taiyuanense (Li) comb. nov., *Chapmanoxylon ? teilhardii* (Sze) comb. nov., *Cordaioxylon sahnii* (Hsu & Bose) comb. nov., and *Cordaioxylon houtouguense* (Zhang & Zheng) comb. nov. were all described as *Dadoxylon* in previous study, their piths and primary xylems

are all known. On one hand, the former two ones have solid (aspetate) piths and endarch primary xylem, which are the general characters of *Chapmanoxylon*; on the other hand, with respect to Pant and Singh's initial aim (Pant & Singh, 1987, p. 70) was to propose this genus for woods which had remained under the name *Dadoxylon*, they are transferred to *Chapmanoxylon*, and furthermore, the cross-field pits of these two species are not certainly numerous and bordered (Fig. 1), which is one of the general features of *Chapmanoxylon*, so that its not surely right to put them in *Chapmanoxylon*, and they should be tentatively treated as doubtful species of the genus.

The later two species, namely *Cordaioxylon sahnii* (Hsu & Bose) comb. nov. and *Cordaioxylon houtouguense* (Zhang & Zheng) comb. nov. have septate piths, so that they accord with the critical general feature of *Cordaioxylon* Grand'Eury and *Solenoxylon* Kräusel. However, as Pant and Singh (1987, p. 69) pointed out, *Solenoxylon* is from the Lower Gondwanas of South West Africa. It shows a large pith with horizontal layers of pith cells and endarch primary xylem. *Cordaioxylon* is northern and its primary xylem may be separated from the secondary xylem by parenchymatous cells

or lie adjacent to it. Obviously, it's reasonable to put these two species, which were previously described as *Dadoxylon*, into *Cordaioxylon*.

PALAEOCLIMATOLOGICAL SIGNIFICANCE: INTERPRETATION ON PALAEOZOIC CLIMATIC CHANGE OF NCB IN THE LIGHT OF FOSSIL WOODS

It is well known that the growth rings in trees generally are the reflection of the fluctuation of climatic conditions. Those in tropical seasonless low latitude zones normally form uninterrupted secondary xylem, whereas those in the savanna belt of the tropics may form faint growth rings, while in seasonal middle-high latitude zones, distinct growth rings usually occur. Although a growth ring might be produced under certain abnormal environmental condition, and even in many plants of northern hemisphere zones, growth rings are produced under all conditions of growth (Esau, 1953), it is widely regarded in palaeobotany as important evidence of climatic conditions (Chaloner & Creber, 1973; Creber & Chaloner, 1984). A good example is the presence of growth rings of the late Permian fossil woods in the Eurammerican and Cathaysian floristic Province have been proved not exceptional but closely connected with the aridization of the climate (Yao *et al.*, 1994).

There are 20 species of fossil woods in total so far on the NCB, they are given in Fig. 7, their localities are shown in Fig. 6, and for stratigraphic position see Fig. 2.

It must be too speculative to interpret the palaeoclimate of the NCB merely based on the state of growth rings in such a large number of fossil woods. However, the development of growth rings generally agreeing with the palaeoclimatic conditions is evidenced by other geological studies and essentially of significance of our attention.

During the Permo-Carboniferous time, the NCB was an isolated island (Fig. 6) in the Palaeotethys. Together with the Yangtze, Jiangnan and Qiangtang blocks, it constituted the Cathaysian Composite Land (Lin, 1989), or so called Cathaysian Landmass Group (Li *et al.*, 1995), which may be regarded as the cradle of the Cathaysian flora. Throughout late Palaeozoic, it experienced a process of northward drifting (Ziegler *et al.*, 1997; Wang *et al.*, 1998, Wang, 1998).

In the late Carboniferous, the whole body of NCB was in a tropical seasonless low latitude zone, and the Cathaysian flora was in its early stage of evolution (Fig. 2; Li, 1997). *Dadoxylon* sp. in this stage from Hongtuwa Formation (= Penchi Formation in N China, about the age of Namurian) in Jingyuan, Gansu, produced uninterrupted secondary xylem.

Approximately in the interval from Stephanian to Asselian (Taiyuan Formation, Fig. 6, C_3-$P_1{}^1$), its main body might enter into the savanna belt of the tropics, therein middle stage Cathaysian flora developed (Li, 1997). Since there was no

remarkable deficiency of water supply, most woods, including *Szeioxylon xuzhouense*, *Shanxioxylon sinense*, *S. taiyuanensi*, *Araucarioxylon yichuanense*, *Cordaioxylon salinii*, *Pennsylvanioxylon* cf. *nauertianum* did not form growth rings; *Zalesskioxylon ningwuense*, *Chapmanoxylon taiyuanensis*, presented indistinct ones; *Pennsylvanioxylon tianii* is interesting for its distinctive growth rings, and this could be the result not of the climatic condition, but of its special living environment in arid high land (Tian & Wang, 1987). Generally, judging from the body-arrangement of the NCB in this stage (Ziegler *et al.*, 1997; Wang, 1998; Fig. 6), as far as such fossil localities as Xuzhou, Yichuan, Zhaozhuang, Yanzhou, Taiyuan and Ningwu were concerned, it is evidenced that the further northward a locality was situated, the more clearly defined its growth rings became. Such a tendency is in agreement with the trend of climatic change along latitudes.

Entering the age from Sakmarian to Artinskian (Shanxi Formation, Fig. 6, $P_1{}^2$), the NCB kept its slowly northward continuous movement. The *Protophyllocladoxylon henanense* from Pingdingshan and *Cordaioxylon salinii* from Taiyuan all produced uninterrupted secondary wood, showing the main body of NCB might have been still located in the middle-low latitude zone. On the other hand, *Zalesskioxylon xiuqiense* and *Cordaioxylon houtoumiaoense* without growth rings occurred from the present Xiwuzhumuqi of Inner Mongolia, and this might represent the southern edge of Angaran land (Zhang & Zheng, 1984), which was neighbouring to the north of NCB. The absence of growth rings may also provide evidence about the NCB not drifting away from low latitude zone. Such a long stay in tropical zone was favourable to the development of Cathaysian flora, with certain typical Cathaysian elements, e.g., *Lepidodendron oculus-felis*, *Lobatannularia sinensis*, *Tingia hamaguchii*, *Emplectopteridium alatum*, *Emplectopteris triangularis* flourishing (Fig. 2).

In such a gradual northward movement, certainly a position geographically more northern would get rid of low latitude zone more earlier. From Kungurian to Kazanian age (Fig. 6, $P_1{}^2$-$P_2{}^1$, Lower and Upper Shihhotse Formation), the Cathaysian flora reached acme. The representative elements of the Cathaysian flora, such as *Lobatannularia heianensis*, *L. ensifolia*, *Gigantonoclea lagrelii*, *G. hallei* and *Fascipteris* were flourishing well. Datong and Wuda probably had moved into middle latitude zone, resulted in the appearance of poorly developed growth rings of *Araucarioxylon neimongense* sp. nov. and *Araucarioxylon wudense* sp. nov., and even well marked ones of *Chapmanoxylon ? teihardii* and *Araucarioxylon* sp. Until the end of Tatarian age (uppermost Upper Shihhotse Formation), the southern edge of NCB started entering into middle latitude zone, one petrified *Dadoxylon*-type fossil wood from Pingdingshan (Sze, 1954) produced growth rings obviously.

There were three species in Shichienfeng Formation (Fig. 6, P_2^2), namely *Araucarioxylon leei*, *Zalesskioxylon yimaense* and *Platyspiroxylon* cf. *heteroparenchymatosum* Greguss, respectively from Yaoxian, Yima and Liulin. They universally formed growth rings, indicating the NCB most probably had reached the arid zone of the Northern Hemisphere, so that vegetation therein was under the periodic deficiency of precipitation. As a result, the Cathaysian flora was subjected to living under new climatic conditions, and inevitably at last the events of community extinction set in. From then on, the palaeophytogeography of the NCB remarkably changed (Wang, 1985, 1989; Li, 1997; Wang *et al.*, 1998).

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