Flora of Palaeozoic coal balls of China

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The geographic distribution of coal balls of China and their stratigraphic range are very wide. Fossil plants in coal balls are abundant. Floras of coal balls of Jingyuan Gansu contain the same content as those of the Hauptfloz coal of Ruhr and the Kokfloz coal of Ostrau (Namur C) in Europe. Coal balls of Shanxi and Shandong (P_1) are abundant and highly diversified with flourished Cathaysian flora, while in the coal balls of Shuicheng, Guizhou (the top of Upper Permian) the Cathaysian flora somewhat declines and shows less in diversification. Some Mesozoic coloured elements have also been observed.

Key-words—Flora, Coal balls, Cathaysian elements, Palaeozoic, China.

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सारांश

चीन की पुराजीवी कोयला कन्दुकों से उपलब्ध वनस्पतिजात

तिआन बावलिन, वाँग शिजुन, गुओ यिंगतिंग, ली हौंगकी, चेन गुइरेन एवं झाओ हाँग

चीन में कोयला कन्दुकों का भौगोलिक वितरण बहुत विस्तृत है। इन कन्दुकों से पर्याप्त मात्रा में अश्मित पौधे मिलते हैं। जिंगियान से एकत्र कोयला कन्दुकों से भी उसी प्रकार का वनस्पतिजात मिलता है जैसा कि रूहर के हॉपफ्लाज कोयलों से तथा यूरोप में ऑस्ट्रो के कोकफ्लॉज कोयलों से मिला है। शाँक्सी एवं शानडाँग से उपलब्ध कोयला कन्दुकों में प्रचुर एवं अत्याधिक विभिन्नता युक्त वनस्पतिजात विद्यमान है जबकि गुइझाउ में शुइचेंग से प्राप्त कुन्दुकों में विद्यमान कैथेसिआ वनस्पतिजात कम विभिन्नता प्रदर्शित करता है। इसके अतिरिक्त कुछ मध्यजीवी युगीन रंगीन अवयव भी प्राप्त हुए हैं।

IN China, Tian and Zhang (1972) were the first who reported the coal balls from Shuicheng, Guizhou, SW China. In the last about 24 years, coal balls have been found from a lot of localities (Li Xingxue *et al.*, 1995; Pan *et al.*, 1985). Geologically and geographically the coal balls are widely distributed in China, including Jingyuan of Gansu, NW China (Namur C); Taiyuan, Lishi, Pingsuo of Shanxi, North China; Zaozhuang, Yanzhou, Xinwen of Shandong, Jiawang, Xuzhou of Jiangsu, Huainan of Anhui (P_1), East China; Shaoyang of Hunan (P_2), South China; and Shuicheng, Panxian of Guizhou, SW China (P_2). Besides, there are some other records from other sites and different horizons, but they have not been studied. The lowest stratigraphic position of coal balls is Namur C of the Upper Carboniferous (Jingyuan, Gansu), while the uppermost one is the top of Upper Permian (Changxing Stage, Shuicheng, Guizhou; Tian *et al.*, 1980; Li Xingxue, 1995). The stratigraphic range of the occurrence of coal balls in western Europe is from Namur C to the end of Upper Carboniferous (Phillips, 1980, 1985). In North America, the stratigraphic range of coal balls is from Westphalian B to Lower Permian (Phillips, 1980, 1985). Cathaysian flora area of China, Eastern Europe and America were located in the same climatic belt (tropic and subtropic belt) in Palaeozoic Era. The research of coal balls is of great importance in understanding the origin and evolution of the terrestrial plants in this part of the Earth. It is significant that coal balls of the above three areas are complementary to one another in stratigraphic horizons, as well as in floral composition.

FLORA IN COAL BALLS OF JINGYUAN, GANSU

As indicated by associated fossil animals, such as : ammonoids, conodonts and foraminifera, the stratigraphic horizon of the coal balls in Jingyuan, Gansu, is referable to Namurian C (Li Xingxue *et al.*, 1995), which is the lowest stratigraphical occurrence of coal balls so far known in China. Outside China, there are only two records from this level, of them one is from Ruhr (Hauptfloz coal) and the other from Ostrau (Koksfloz). Both of them belong to Namurian C (Phillips, 1980, 1985). The coal balls of Jingyuan mainly contain *Lepidodendron (Diaphorono-dendron)* cf. *vasculars* Binney, *Lepidodendron* sp., *Stigmaria* sp., *Myriophylloides* (*Calamites* root), Zygopleridaceae, *Dadoxylon* (*Mesoxylon*?) sp.,

The coal ball flora of Jingyuan is not very abundant. This character is similar to that of Ruhr and Ostrau. The composition of fossil plants in coal balls of these three sites is the same, and denotes that the regional differentiation of tropic and subtropic climate belt was indistinct. Thus, all the floras flourished in similar environments.

The quantitative analysis of fossil plants from Jingyuan made by Tian (Li Xingxue *et al.*, 1995) shows that lycopsids (including *Lepidodendron* and *Stigmaria*) are most abundant (up to 75 %) followed by calamophytes and cordaitopsids; filices are small and few and some of them might probably be epiphytes. In Tian's opinion (Li Xingxue *et al.*, 1995), it represents a water abundant peat bog vegetation in the paralic area.

FLORA IN COAL BALLS OF TAIYUAN, SHANXI AND ZHAOZHUANG, SHANDONG

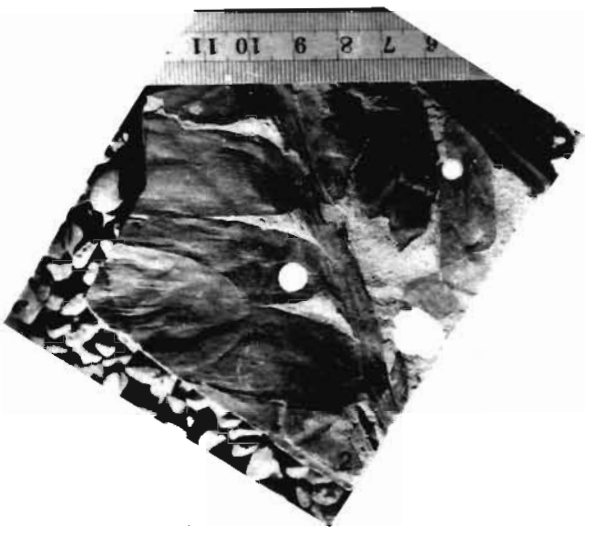
Coal balls of Xishan, Taiyuan, Shanxi Province and N. China were found in the Coal seam no. 7 of the Dongdayao Member of the Taiyuan Formation. The stratigraphic position, as determined by fusulinids and brachiopods, etc. collected from its roof and bottom beds, is Lower Permian (*Pseudo-schwagerina* zone) that can be compared with Middle and Upper Wolfcampian Group of U.S.A. (Pan *et al.*, 1985; Li Xingxue *et al.*, 1995). The flora in the coal balls of Taiyuan has been studied in detail by several workers in China (Tian Baolin *et al.*, 1987, 1988; Wang Shijun *et al.*, 1993, 1995a, 1995b; Zhao Liming, 1989; Guo Yingting *et al.*, 1990; Li Xingxue *et al.*, 1995). The main elements of the flora are as follows:

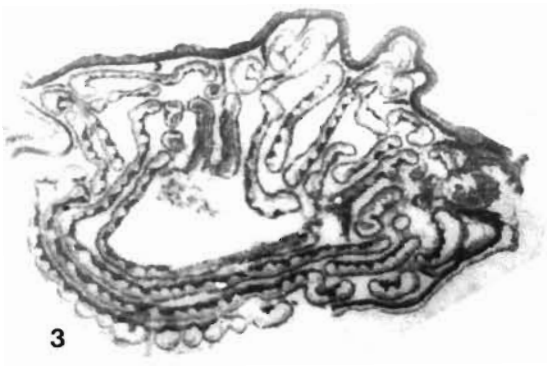
Lepidodendron (*Diaphorodendron*) cf. *scleroticum* Pannell, *Lepidodendron* spp., *Achlamydocarpon* sp.1, *Achlamydocarpon* sp. 2, *Stigmaria ficoides* (Sternb.) Brongn., *Stigmaria* sp., *Sphenophyllum plurifoliatum*, *Sphenophyllum* sp., *Arthropitys* sp., *Asteromyelon williamsonii* Reed, *Artromyelon* sp., *Etapteris* sp., *Anachoropteris* sp., *Botryopteris* sp., *Psaronius* sp. 1 (sp. nov.), *Psaronius* sp. 2 (sp. nov.), *Psaronius* sp., *Pecopteris* sp., *Scolecopteris* sp. 1, *Scolecopteris* sp. 2, *Stipitopteris* sp., Lyginopteridaceae, *Kaloxylon* sp., *Rhatinan-gium* sp., *Medullosa* sp., *Pennsylvanioxylon tianii* Tian et Wang, *P. nauertianum* (Andrews) Costanza, *Shanxioxylon sinense* Tian et Wang, *S. taiyuanense* Tian et Wang, *Cordaianthus ximinensis* Wang et Tian, *C.* cf. *concinnus* Delevoryas, *Cardiocarpus samaratus* Wang et Tian, *Cordaites taiyuanensis* Wang et Tian, *Cordaites* sp. 1, *Amyelon iowense* (Pierce et Hall), *Amyelon taiyuanense* Wang et Tian, *Amyelon* spp., *Mitrospermum* sp., *Lagenostoma* sp., *Callospermarion sinicum* Zhao, *Araucarioxylon*? sp., etc.

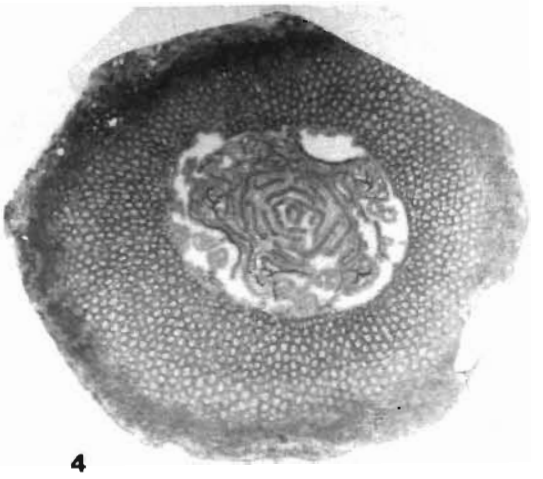
The flora is dominated by cordaitopsids and lycopsids. Both these groups are of big trees and their remains are abundant in coal balls of coal seam no. 7. According to the quantitative analysis made by Wang Shijun *et al.* (1995b) on the peelings (total area

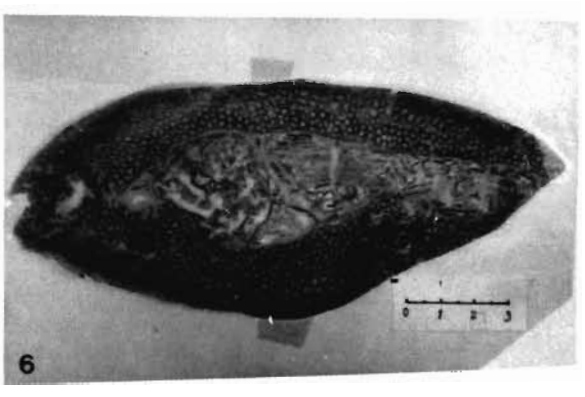
PLATE 1

1. *Plagiozamites* sp. transverse section of rachis, X 50, Panxian, Guizhou, P_2.
2. *Plagiozamites oblongifolius*, X 0.6, Panxian, Guizhou, P_2
3. *Compsopteris* sp. transverse section of rachis, X 20, Panxian, Gui zhou, P2.
4,5. *Psaronius wangii* transverse section of stem, Panxian, Guizhou, P_2.
4. Type specimen, X 1/2.8.
5. Transverse section of the upper part of the stem, X 0.5.
6. *Psaronius magnificus* transverse section of the stem, X 0.45, Panxian, Guizhou, P_2.
7. *Achlamydocarpon sinensis* transverse section, X 24, Shuicheng, Gui zhou, P_2









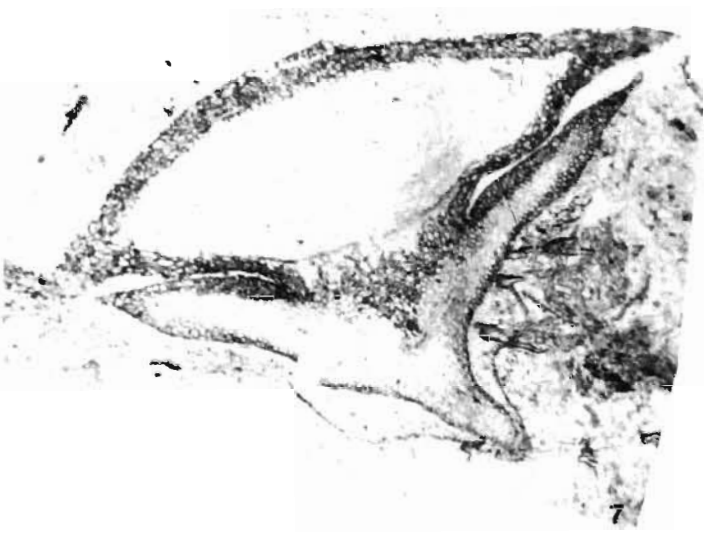


PLATE 1

not less than 2 m^2) coming from hundreds of coal balls, cordaitopsids and lycopsids make up 60-70 per cent of total biomass, *Psaronius* 10-20 per cent, the rest 10 per cent by other plants. Among the dominant plants, cordaitopsids have a highest percentage up to 65 per cent, and lycopsids of about 35 per cent. Superficially this ratio of fossil plants in the coal balls is similar to that of the flora in coal balls of Westphalian C-D in the Euramerican phytogeoprovince (Phillips, 1980), but with some differences, especially in case of *Psaronius* and the occurrence of *Medullosa*. According to Phillips (1980), filices in Westphalian flora were not more than 5 per cent and at the end of Westphalian reached up to 10 per cent. It was in Stephanian when filices reached their climax. *Medullosa* became abundant only with the prosperity of *Psaronius*. Obviously, the age represented by the flora in the coal balls of Taiyuan is younger than Westphalian.

In Euramerican phytogeoprovince, the climate became dry in Stephanian. It was obviously drier in Permian due to which the flora had much changed. Cathaysian phytogeoprovince in the Early Permian was still in humid climatic environment of tropic and subtropic, and belts, swamps and peat bogs still spread everywhere. Therefore, cordaitopsids and lycopsids dominated the flora, but some important changes indeed occurred in the composition of the flora.

The flora in coal balls of Shandong comprises a number of typical elements of Cathaysian lycopods, such as: *Lepidodendron oculus-felis, L. posthumii, L. szeianum, L. tachingshanense* and *Cathaysiodendron incertum*.

The palaeoecology of cordaitopsids in coal balls of Taiyuan has also been studied. According to Wang and Tian (Wang *et al.*, 1995b), aerenchyma tissue developed in the roots of *Amyelon taiyuanense* and *A. iowense*, which indicates that these plants suitably lived in swamps and bogs of salt water and brackish area. In the roots of *Amyelon* sp. 1, no aerenchyma tissue exists which shows that *Shanxioxylon taiyuanense* might lived in the areas of the margin of swamps and peat bogs and the higher lands in swamps and peat bogs. In the peat bog of Early Permian of Taiyuan, the vegetation might be dominated by the small trees of cordaitopsids.

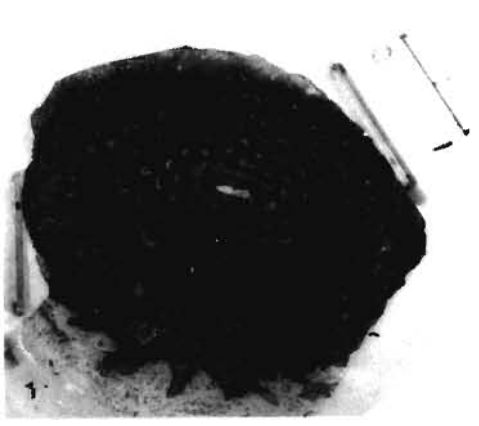
FLORA IN COAL BALLS OF SUICHENG, GUIZHOU

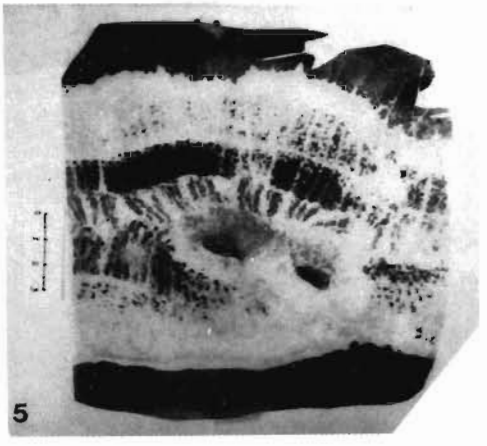
The highest stratigraphic horizon of coal balls is from Wangjiazhai, Shuicheng of Guizhou Province, SW China. The coal-bearing coal balls is number $C_{60}5$. The bottom bed of coal seam no. 1 ($C_{60}5$) yields fossil ammonoids including *Pleuronodoceras, Rotodiscoceras, Pseudotirolites*, etc. and fusulinids such as *Palaeofusulina fusiformis, P. nana*, etc. (Tian Baolin *et al.*, 1980). The roof bed of coal seam no. 1 ($C_{60}5$) is the Lower Triassic limestone in which some Triassic fossil bivalves are yielded. Between coal seam no. 1 ($C_{60}5$) and the Lower Triassic limestone there exists a thin layered mudstone (more than 20 cm in thickness) which yielded fossil plants such as *Lepidodendron oculus-felis*, etc. It shows that coal balls of $C_{60}5$ are from the uppermost horizon of Palaeozoic in China as well as in the world (Tian Baolin & Zhang Lianwu, 1980; Li Xingxue *et al.*, 1995).

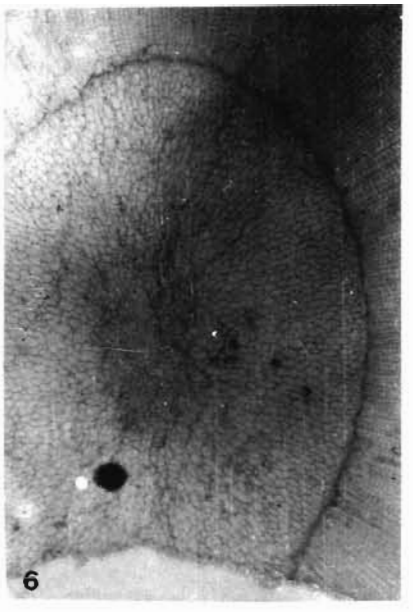
The flora in coal balls of Shuicheng, China has been studied in detail. Quite a few fossil plants were incompletely preserved, but fortunately there existed petrified fossil plants that help identifying the fragment of fossil plants in coal ball. The composition of flora in coal balls, as studied by Tian Baolin and Guo

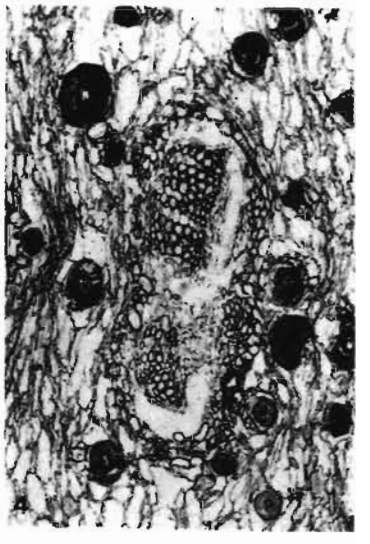
PLATE 2

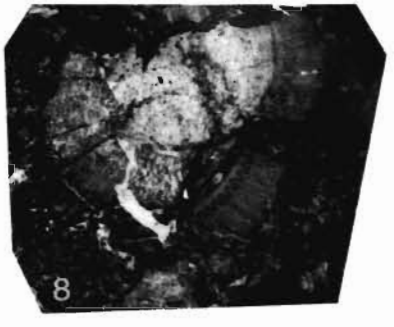
1, 2. *Palaeosmunda xui* (sp. nov.), Xuanwei, Yunnan, P_2
1. Transverse section of the stem, X 1
2. Part of the stem in transverse section, showing the leaf traces in the cortex, X 25.
3, 4. *Yunnania sinense* gen. et sp. nov., Xuanwei, Yunnan, P_2.
3. Transverse section of a branch, X 2.2.
4. Showing the leaf traces in the cortex, X 25.
5, 6. *Lepidodendron posthumii*, Zhaozhuang, Shandong, P_2.
5. Transverse section of a trunk, X 0.3.
6. Showing the protostele, X 6.5.
7. *Sphenophyllum pluritoliatum*, transverse section of the stem, X 25, Taiyuan, Shanxi. P_1.
8, 9. *Sigillaria* cf. *brardii*, Shuicheng, Guizhou, P_2.
8. Transverse section of the stem, X 1.
9. Part of the stem, showing the xylem, X 10.

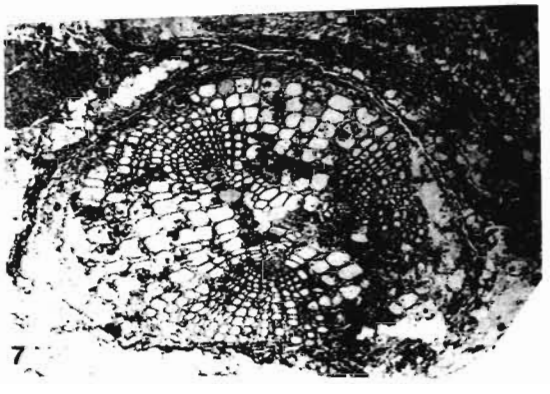












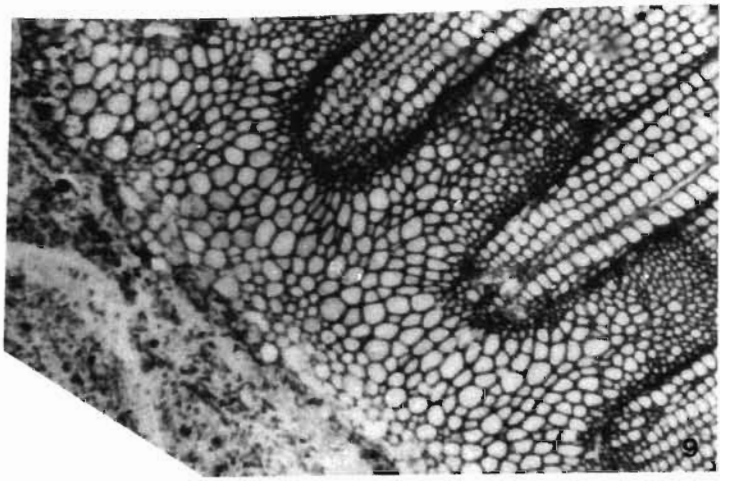


PLATE 2

Yingting and partially examined by Phillips is as follows (Li Xingxue *et al.*, 1995):

Lepidodendron oculus-felis, L. acutangulum (Halle) Stockm. et Math., *L. asymmetricum* Gu et Zhi, *L. lepidophloides* Zhang, *Lepidodendron* sp. 1 (sp. nov.), *Lepidodendron* sp. 2, *Sigillaria* sp., *Sigillaria* cf. *brardii, Achlamydocarpon sinensis* Tian et Guo, *Achlamydocarpon* sp., *Marzocarpon* sp., *Stigmaria ficoides* (Sternb.) Brongn., *Stigmaria* sp., *Sphenophyllum* sp., *Arthropitys yunnanensis* Tian et Guo, *Arthropitys* sp., *Stipitopteris* sp., *Scolecopteris* spp. *Compsopteris elliptica* (Chang) Yang et Chen, *Compsopteris* sp., *Anachropteris* sp., *Botryopteris* sp., *Shuichengella primitiva* Li, *Palaeosmunda xui* Tian et Chang, *Palaeosmunda plenacioides* Li, *Palaeosmunda* sp., *Plagiozamites oblongifolius* Halle, *Plagiozamites* sp., *Amyelon xui* Li, *Amyelon?* sp., *Araucarioxylon* spp., gigantopterids and gymnosperms (including pteridosperms, cordaitopsids?, cycadophytes, coniferophytes, probably ginkgopsids, etc.).

The Shuicheng coal ball flora exhibits that after the prosperous stage in Early Permian and the high prosperous and diversification stage in early Late Permian, the Cathaysian flora still remained in vigorous condition. Though a great change occurred in late Late Permian, including the decrease in the number of genera and species and the relatively impoverishment of composition of the flora. In the flora, Cathaysian elements played a leading role, but Mesozoic elements like cycadophytes, coniferophytes, probably ginkgopsids developed much. Some highly evolved elements of filices also came into existence, such as *Palaeosmunda*. It shows that it was the latest flora of Palaeozoic.

A quantitative analysis of the flora denotes that the flora in coal balls of Shuicheng exhibits the prevalence of tropic and subtropic climate, but the distinct growth ring in the cross section of the stem of some plants reflects the character of seasonal rainforest climate. It also indicates that in late Late Permian the climate had already shown an omen of drying in Early Triassic.

CONCLUSION

As shown by the study of the coal ball flora of China, the time of development of the Cathaysian flora must be after Namur. Perhaps it developed in Westphalian. Through Westphalian and Stephanian, Cathaysian flora developed and proliferated. In Early Permian, flora in coal balls became prosperous and much diversified. In the early Late Permian, Cathaysian flora reached at its climax with diversification, but coal balls had been found very few. In late Late Permian the Cathaysian flora declined in the number of genera and species and some Mesozoic coloured elements increased. By the end of Late Permian, the Cathaysian flora became extinct.

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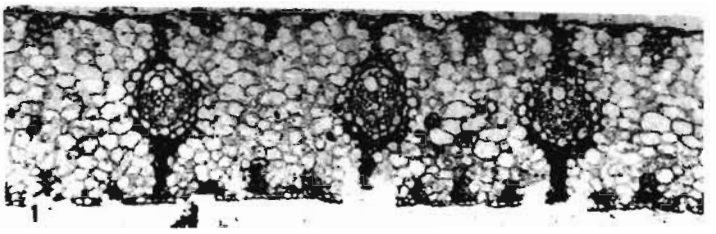
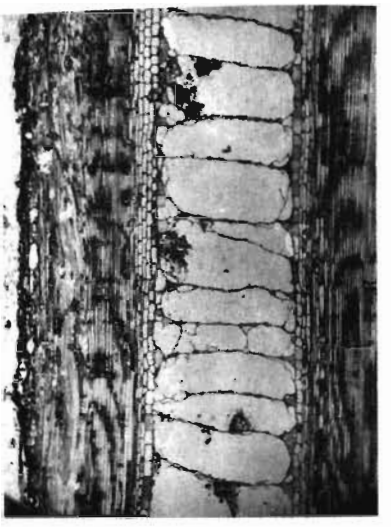
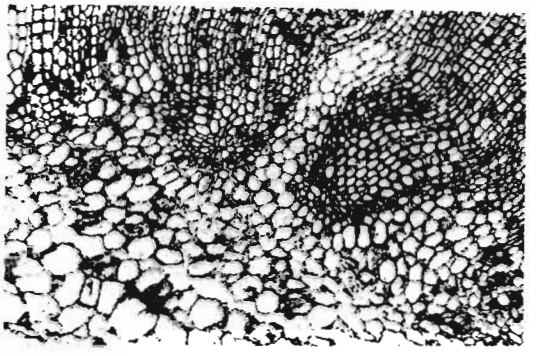
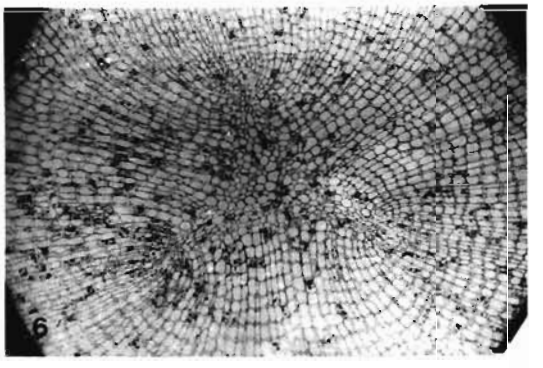
PLATE 3

1. *Cordaites taiyuanensis* transverse section of the leaf, X 40, Taiyuan, Shanxi, P_1.
2. *Shanxioxylon sinense* transverse section of the stem, X 4.5, Taiyuan, Shanxi, P_1.
3. *Pennsylvanioxylon tianii* radial section of the stem, X 16, Taiyuan, Shanxi, P_1.
4. *Shanxioxylon taiyuanense* transverse section of the stem, X 40, Taiyuan, Shanxi, P_1
5. *Cordaianthus* cf. *concinnus* longitudinal section of a reproductive dwarf shoot, X 15, Taiyuan, Shanxi, P_1.
6. *Amyelon taiyuanense* transverse section of a large root, X 16, Taiyuan, Shanxi, P_1
7. *Cordaianthus xishanensis* oblique section of a reproductive dwarf shoot, X 12, Taiyuan, Shanxi, P_1
8. *Cordaianthus rament-rarus* transverse section of a reproductive dwarf shoot, X 15, Taiyuan, Shanxi, P_1.
9. *Cardiocarpus samaratus* longitudinal section in secondary plane, X 16, Taiyuan, Shanxi, P_1.









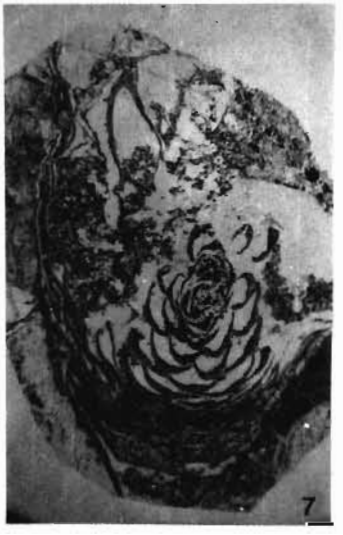


PLATE 3

Tian Baolin & Wang Shijun 1987. On the cordaitean stems in coal balls from Taiyuan Formation in Xishan, Taiyuan, Shanxi. *Acta palaeont. sin.* **26**(2) : 196-204 (in Chinese with English Abstract).

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