A preliminary study on the Stephanian flora of China

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Liu Huaqing & Shen Guanglong 1996. A preliminary study on the Stephanian flora of China. *Palaeobotanist* **45** : 233-237.

Since the Taiyuan Formation used to be regarded as of Upper Carboniferous has proved to be a diachronous rock-stratigraphic unit, the formerly so-called Stephanian flora of China mostly contained in this formation needs be critically restudied. This paper attempts to show some aspects (composition, character and phytoprovince etc.) of the Stephanian flora in the strict sense.

Key-words—Palaeobotany, Plant megafossils, Stephanian flora, Zone, Phytoprovince.

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सारांश

चीन के स्टीफानियन वनस्पतिजात का प्रारम्भिक अध्ययन

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चूँकि उपरि कार्बनीफेरस ताइयुआन शैल-समूह को एक चटटान स्तरिकीय इकाई के रूप में प्रस्तावित किया गया है, इस शैल-समूह से प्राप्त स्टीफानियन युगीन वनस्पतिजात का विशेष रूप से अध्ययन किया जाना आवश्यक है। प्रस्तुत शोध-पत्र में स्टीफानियन वनस्पतिजात के लक्षण, संरचना एवं पादप-प्रान्तों जैसे कुछ पहलुओं पर विवेचन का प्रयास किया गया है।

PREVIOUSLY in the literature, the basic concept concerning the Stephanian flora of China was always linked with those of the Yuemenkou Flora studied by Halle (1927), the Linxi Formation Flora by Stockmans et Mathieu (1939, 1957) and the Early Cathaysian Flora, or the *Neuropteris pseudovata-Lepidodendron posthumii* Assemblage of Lee (1963). It has been indicated, however, that the lithostratigraphic unit defined by these so- called Stephanian floras contains the Late Carboniferous fusulinid *Triticites* Zone and Early Permian fusulinid *Pseudoschwagerina* Zone. In other words, most of the Yuemenkou Series belongs to the Lower Permian, only the lower part of the Taiyuan Formation, i.e., the Jinxi Member (*Triticites* Zone), is the representative of Stephanian deposit in China. Based on an analysis of the related data, the composition, the character and the phytoprovince of the Stephanian flora of China have been described briefly in the present communication.

DISTRIBUTION OF STEPHANIAN FLORA IN CHINA

The truly Stephanian plants of China, according to available collections, exist mainly in the North China Platform (including the northern Qilian Mountains) and the Junggar-Hinggan region. The principal localities of the Stephanian flora of China are listed in Table 1.

BOTANICAL CHARACTERS OF STEPHANIAN FLORA IN CHINA

The Stepanian flora of China, as now known, comprises 19 genera belonging to 59 recognizable species which can be classified into the following plant groups:

Lycopsida :	4 genera, 15 species
Sphenopsida:	4 genera, 14 species
Noeggerathiopsida:	2 genera, 5 species
Filices et Pteridospermopsida:	8 genera, 23 species
Cordaitopsida:	1 genus, 2 species

From this list, it may be concluded that the dominant group of the flora is dominated by Filices and Pteridospermopsida followed by Lycopsida and Sphenopsida respectively.

All of the lepidophytic plants, probably excepting *Lepidodendron gaudryi*, are endemic Cathaysian. Such forms as *L. oculus-felis, L. posthumii, L.szeianum* and *Cathaysiodendron nanpiaoense* are the most significant species of the Cathaysian flora with their wide distribution in North China and Northwest China, and extend stratigraphically upward into the Asselion.

The Filices and Pteridospermopsida form 37.2 per cent of the entire flora, among them the genus *Pecopteris* including 14 species, is the most important, which is similar to that of Euramerican flora. In Neuropterides, with the exception of *Paripteris pseudogigantea*, the Parispermae disappeared, but the Imparispermae represented by *Neuropteris pseudovata* and *N. plicata* are abundant. The net-veined *Linopteris brongniartii* deserves attention, it used to be regarded as one of the typical representatives of the Westphalian stage of China, but based on collected data it persists undoubtedly into the Stephanian. *Alethopteris*, a most common form of the Stephanian flora in Euramerica, is rare in China; only *A. huiana* Lee first occurs in the Stephanian.

Five species of the genus *Sphenophyllum* were found in the Stephanian flora, i.e., *S. emarginatum, S. oblongifolium, S. verticillatum, S. laterale,* and *S. kawasakii*. The first three are common elements of the Euramerican flora, the last two the endemic species of China. Among the Equisetales, the leaf-impressions represented by *Annularia pseudostellata, A. stellata* and *Asterophyllites longifolium* are relatively more abundant than that of the pits-cast, which with only a few specimens of *C. cistii* and *C. suckowii* discovered.

Tingia, being regarded as a genus of the Noeggerathiopsida, is one of the typical elements of the Cathaysian flora and appeared in the Late Namurian. In the Stephanian, it started to diversify rapidly and at least three species, namely, *T. carbonica, T. partita* and *T. trilobata* appeared. *Conchophyllum,* another genus of the Noeggerathiopsida, is an important member of the Early Cathaysian flora and its type-species, *C. richthofenii* Schenk has been considered as one of the index species of the Benxi Formation or the Yangtugou Formation (Westphalian). *C. parvifolium* was first found by Bohlin (1971) in the Bed 7 (Yangtugou Formation) of Yuerhung, Gansu Province. The existence of the two species in the Stephanian flora shows that *Conchophyllum* had its maximum development in the Westphalian, but it may extend upwards into the Stephanian.

To sum up, the characters of the Stephanian flora of China can be listed as follows:

1. The genus *Pecopteris* is the most common form and shows an affinity with the typical Euramerican flora, only a few endemic species occur.
2. The genus *Tingia* had appeared and started to diversify, but did not reach its climax. *Conchophyllum* still existed but disappeared completely by the end of the Stephanian.
3. Besides *Lepidodendron gaudryi*, common to both the Cathaysian and Euramerican floras, the other Lepidophytic plants tend to give the Stephanian flora of China an aspect of typical Cathaysian affinity, and do not have infrafoliar scars in the leaf cushions.
4. The very typical forms of the Middle Cathaysian flora, such as *Emplectopteris triangularis* Halle, *Emplectopteridium alatum* Kawasaki, *Alethopteris hallei* (Jongmans et Gothan) Stockmans et Mathieu and *A. norinii* Halle had not appeared in the Stephanian.

RELATIONSHIP BETWEEN STEPHANIAN FLORA OF CHINA AND EURAMERICA

As shown in Table 1 that the Stephanian flora of China and that of Euramerica comprise such common forms as *Lepidodendron gaudryi* Renault, *Sphenophyllum emarginatum* Brongniart, *S. oblongifolium* (Germar et Kaulfuss) Unger, *S. verticillatum* (Schlotheim) Brongniart, *Stigmaria ficoides* (Sternberg) Brongniart, *Calamites cistii* Brongniart, *C. suckowii* Brongniart, *Annularia galioides* (Lindley et Hutton) Kidston, *A. pseudostellata* Potonie, *A.. stellata* (Schlotheim) Wood, *Pecopteris arborescens* (Schlotheim) Sternberg, *P. hemitelioides* Brongniart, *P. feminaeformis* (Schlotheim) Sterzel, *P. lepidorachis* Brongniart, *P. unita* Brongniart, Neuropteris plicata Sternberg, *Linopteris brongniar-*

Table 1 The localities of the Stephanian Flora of China

1. Nanpiao Coai Field, Liaoning, 2. Kaiping Basin, Hebei, 3. Liujiang Basin, Hebei, 4. Taiyuan, Shanxi, 5. Baode, Shanxi, 6. Southeastern Shanxi, 7. Zibo, Shandong, 8. Weibei Coal Field, Shaanxi, 9. Jungar, Inner Mongolia, 10. Helan Mountains, Ningxia, 11. Zhongwei, Ningxia, 12. Northwestern Qilian Mountains, Gansu, 13. Longshou Mountains, Gansu.

FOSSIL PLANTS \ LOCALITIES	1	2	3	4	5	6	7	8	9	10	11	12	13
LYCOPSIDA													
Lepidodendron carinum Lee									√			√	
L. galeatum Gu et Zhi									√				
L. gaudryi Renault				√									
L. hunjiangense Huang									√				
L. nunghsiaense Sze et Lee									√				
L. oculus-felis (Abbado) Zeiller		√		√		√	√	√	√	√	√		
L. posthumi Jongmans et Gothan			√	√				√	√	√		√	
L. subrhombicum Gu et Zhi									√				
L. steinmanni Lee									√				
L. volkmannianum Sternberg									√				
Cathaysiodendron acuminatulatum (Halle)		√											
C. incertum (Sze et Lee)Lee												√	
C. nanpiaoense Lee				√				√				√	
Ulodendron tieni Lee				√					√				
Stigmaria ficoides (Sternberg) Brongniart	√						√	√					
SPHENOPSIDA													
Sphenophyllum emarginatum Brongniart		√		√				√	√				
S. kawasakii Stockmans et Mathieu									√				
S. laterale Sze								√					
S. oblongifolium (Germar et Kaulfuss)		√		√	√	√		√	√	√	√	√	√
S. verticillatum (Schlotheim)Unger						√							
Calamites cistii Brongniart								√	√				√
C. suckowii Brongniart												√	√
Annularia galioides (Lindley et Hutton)		√											
A. gracilescens Halle		√											
A. papiliformis Kawasaki		√											
A. pseudostellata Potonie				√						√			
A. stellata (Schlotheim) Wood		√					√	√				√	
Asterophyllites equisetiformis (Schlotheim)						√						√	
A. longifolius (Sternberg) Brongniart												√	
NOEGGERATHIOPSIDA													
Tingia carbunca (Schenk) Halle										√		√	
T. partita Halle		√											
T. trilobata Stockmans et Mathieu		√										√	
Conchophyllum parvifolium Baldin												x	
C. richthofeni Schenk												√	
FILICES ET PTERIDOSPERMOPSIDA													
Sphenopteris nemeroglomus Huang			√										
S. nystromi Halle			√										
S. tenus Schenk			√										
Pecopteris affinis Brongniart		√											
P. arborescens (Schlotheim) Sternberg				√								√	
P. arcuata Halle		√											
P. candolleana Brongniart					√			√			√	√	
P. cyathea (Schlotheim) Brongniart	√		√	√				√				√	√
P. feminaeformis (Schlotheim) Stetzel		√	√							√			√
P. hemitelioides Brongniart	√												
P. lepidorachis Brongniart		√											
P. linsiana Stockmans et Mathieu		√						√					
P. luana Lee												√	
P. moroi Zeiller		√											
P. polymorpha (Brongniart) Stetzel									√				
P. qinglongensis Zhang et Shen												√	
P. unita Brongniart										√		√	
Neuropteris plicata Sternberg				√	√	√		√	√	√			
N. pseudovata Gothan et Sze	√	√	√	√	√	√	√	√	√	√	√	√	√
Parapteris pseudogigantea Potonie												√	
Linopteris brongniarti Gutbier		√	√										
Alethopteris lusina Lee				√		√							
Callipteridium koraiense (Tokunaga)					√	√				√			
CORDAITOPSIDA													
Cordaites principalis (Germar) Geinitz									√			√	√
C. schenkii Halle		√					√						

tii Gutbier and *Cordaites principalis* (Germar) Geinitz. Amongst them, the Pecopterides represented by the *P. arborescens-cyathea* group are most striking and they not only occur numerously in the Rive de Gier of France, the Stephanian beds of Northwestern Spain, the upper part of the Conemaugh Group and the Monongahela Group of North America, but also in the Jinci Member of the Taiyuan Formation and its equivalent strata both in North China and in Northwest China. *Sphenophyllum oblongifolium* (Germar et Kaulfuss) Unger, *S. emarginatum* Brongniart and *Annularia stellata* (Schlotheim) Wood seem to have flourished similarly to the *P. arborescens-cyathea* group. In this case, both Stephanian floras are alike. Even so, we must note the fact that most members discussed here already occured in the Westphalian D of Euramerica, but they were less common in the same time in China. On the basis of this we may conclude that these plants may have originated in Euramerica and then migrated to China.

Besides those common species, there are some obvious defferences between the two floras. It is well known that the Euramerican Stephanian flora is characterized by the co-flourishing of *Pecopteris, lethopteris, Odontopteris* and *Callipteridium*. Among the four, *Pecopteris* is relatively abundant in China. But *Odontopteris*, second only to *Pecopteris* in Euramerica, is completely absent and does not arise until the middle Early Permian (Shansi Formation). So it seems that China's *Odontopteris* is also an immigrant. Why *Odontopteris* arrived later than *Pecopteris*, might be because it evolved later, as *Odontopteris* did not appear untill Stephanian in North America (Darran, 1969). Apart from *Callipteridium trigonum* Franke, which was once found in the west mountain of Taiyuan (Halle, 1927), the other more common forms of the Euramerican flora such as *C. gigas* Gutbier and *C. pteridium* (Schlotheim) Zeiller have not been found hitherto in China, but a few endemic species, for example, *C. koraiense* (Tokunaga) Kawasaki had occured in the Stephanian of North China.

Taeniopteris represented by *T. jejuna* Grand' Eury is a characteristic Stephanian B species from Northwestern Spain (Wagner *et al.*, 1979), and the Rive de Gier of France (Bertrand, 1937). In Stephanian C of Europe, *T. multinervis* Weiss emerged. While in China, *Taeniopteris* appears as fragments in the early Early Permian (middle-Upper

Taiyuan Formation). It is clear that the earliest occurence of *Taeniopteris* of Euramerica is earlier than that in China.

The genus *Alethopteris* has been recorded in the Namurian of Europe (Wagner, 1979) and becomes common in the Stephanian (the most important species are *A. grandini* (Brongniart) Goeppert, *A. zeilleri* Rogot and *A. bohemica* Franke). All species of this genus in China are endemic. With the exception of *A. huiana* Lee, which can be found in the Stephanian beds of the Taiyuan and Kaiping Basins, many significant members including *A. ascendens* Halle, *A. hallei* (Jongmans et Gothan) Stockmans et Mathieu and *A. norinii* Halle first appear in the middle-upper part of the Taiyuan Formation, and flourish in the Shansi Formation and the Lower Shihotze Formation .

The most important coal-forming arborescent lepidophytes in Westphalian of Euramerica started to decline obviously in the Stephanian, only *Lepidodendron gaudryi* Renault and *Sigillaria brardi* Brongniart continued to this time. On the contrary, the most striking oriental-type Lepidophytes, comprising 25.4 per cent of the entire flora, boomed over North China during Stephanian. Such form as *L.oculus-felis, L. posthumii, L. szeianum, C. nanpiaoense* and *C. incertum* are the most common representatives in Cathaysian land, that is why Lee (1963) regarded them as the typical elements of the Early Cathaysian Flora.

Tingia and *Conchophyllum* only occur in eastern Asia there are no similar genera in the Euramerican Flora. In this aspect, the Stephanian flora of China and that of Euramerica are quite different.

PHYTOPROVINCE OF STEPHANIAN FLORA OF CHINA

According to Table 1 and the above discussion, the Stephanian flora of North China and Northwest China includes a number of Euramerican species, i.e., 30.5 per cent to the whole flora. Under this circumstance, the Stephanian flora of China and that of Euramerica exhibit a more or less affinity, that is why some palaeobotanists call them together Euramerisch-Cathaysische Floren Provice (Remy *et al.*, 1977) or Amerosiana Flora (Pfefferkorn *et al.*, 1980). Meanwhile Chaloner *et al.* (1973) believed that the Cathaysian flora had diversified from the common *Lepidodendropsis* flora during the Westphalian stage, because some endemic forms of Cathaysian land occurred.

Apart from *Tingia* and *Conchophyllum*, many other Cathaysian memebers, including *L. oculus-felis, L. posthumii, Cathaysiodendron nanpiaoense* and *C. incertum*, emerged and were widely distributed in Stephanian. They have not been found so far in the Euramerican continent. This certainly shows that the two Stephanian floras are different. Furthermore, some significant plants of the Euramerican flora, i. e., *Alethopteris, Callipteridium* and *Odontopteris* are rare in China. We should not include the flora of China into that of Euramerica just because of species in common.

Though the Cathaysian flora had emerged in the Stephanian, it must be noted that this flora differs greatly from that of the Early Permian, whose characteristic genera are *Emplectopteris* and *Emplectopteridium*, and also from that of the Late Permian characterized by the *Lobatannularia, Fascipteris, Gigantonoclea, Gigantopteris* and *Otofolia*. A few members of the Cathaysian flora, according to rencent studies (Chen *et al.*, 1995), have been found in the Namurian, but they are still scarce. From the beginning of the Stephanian, more and more endemic forms mainly the Noeggerathiales and the Lycopsida, came into being and flourished. This is the origin of the typical Early Cathaysian Flora.

In addition to North China and Northwest China, there are some Stephanian plants to be found in Junggar-Hinggan Hercynian Fold Belt (Dou Yawei *et al.*, 1985). Because of the existence of *Angaropteridium, Angaridium* and *Paracalamites*, they may be regarded as the representatives of the Angara flora. In Stephanian, south China was covered by sea water, since no fossil plants have been discovered so far.

ACKNOWLEDGEMENTS

We thank Dr J. Rigby for critically going through the manuscript and helpful suggestions. This reseach is financially supported by the China National Natural Science Foundation (Grant No. 49472126).

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